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Senior Scientific Officers
on the Staff of the Ministry of Agriculture and Fisheries

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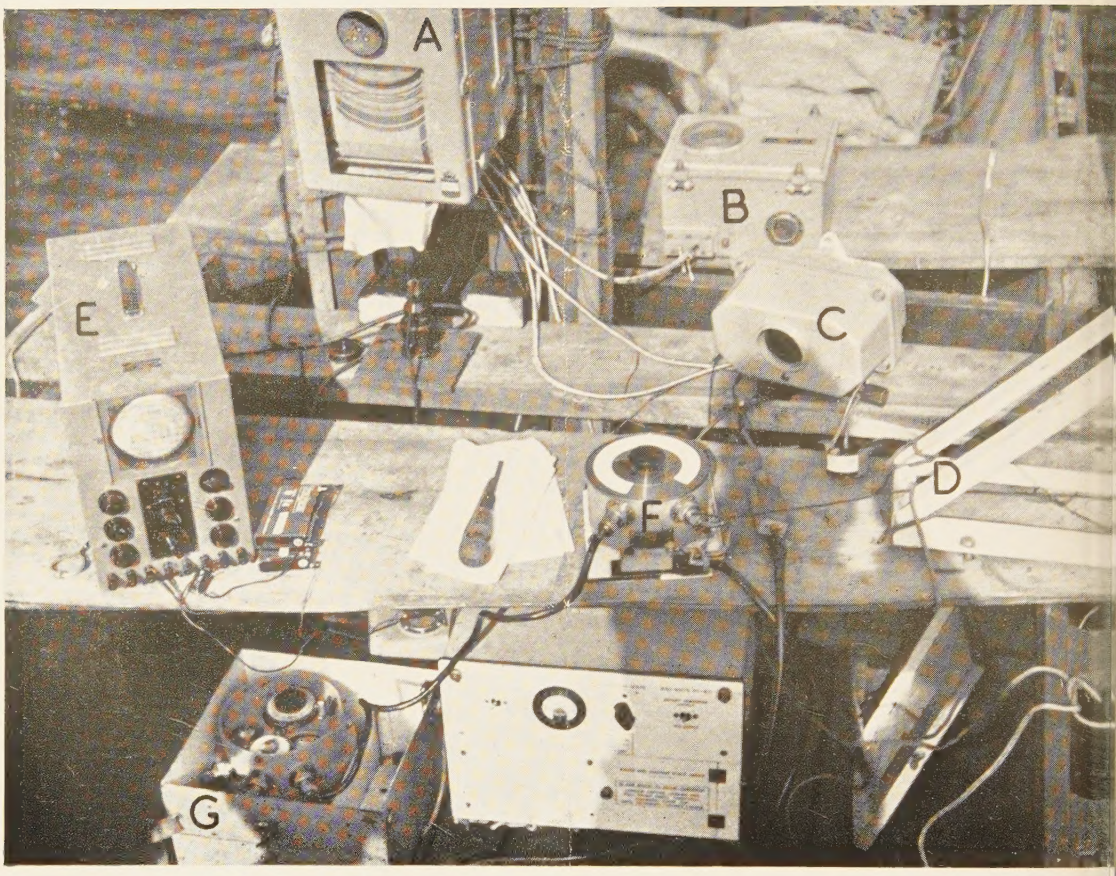

Frontispiece : Photograph of the working arrangement.

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PART I

E PROBLEM, METHODS, AND TREATMENT OF RESULTS

1. INTRODUCTION

ɔcent years the navigational echo sounder has been used for a number of essentially biological ıoses. The most important of these is its use by the fishermen; a large proportion of pelagic rmen and many demersal fishermen now use echo sounders as part of their fishing equipment. e are three ways in which this is done. On the one hand, driftermen tend to use fish traces as ddition to their older signs of fish; when they shoot their two miles of net on to an echoed fish l, they do not so much expect to catch fish from that shoal, as to be in an area where fish are lly abundant. On the other hand, purse-seiners, ring netters, and pelagic trawlers use the ıder as a search instrument and hope to catch the actual fish indicated (Skipper George Leslie us that this is also true for the driftermen off the west coast of Scotland). A third method of g the echo sounder in pelagic fisheries is to use it as a survey instrument; that is to say, searching ɔehalf of the whole fleet is carried out by one ship and the area of most probable abundance is ıd. Then the fleet need to fish in this area only.

research, there are three directions of work connected with fish behaviour and distribution, t from that concerned with fishing. The first of these is concerned with the responses of pelagic to daylight, artificial light, and ultra violet light (Tester, 1943*a* and *b*; Hodgson and Richardson, ; de Boer, 1950; Krefft and Schubert, 1950; Schüler and Krefft, 1951; Richardson, 1952; ;, 1952) ; here the minimum depth of the fish traces is observed to change as lights are switched r off. The second type of work is the study of the vertical migration of fish; herring, pilchard, sprat shoals have been observed at different levels by night and day (Hodgson and Richardson, , Krefft and Schüler, 1951*b*, Schüler, 1951*b*, Schüler and Krefft, 1951, and Richardson, ., have demonstrated migrations of continuous shoals of sprats and herring). The third type ɛsearch is that concerned with the scattering layer; here vertically migrating layers, usually se in character and often unidentified, have been observed over very wide areas of sea and n (Hersey and Moore, 1948; Dietz, 1948; Moore, 1950; Boden, 1950; Tchernia, 1951; l and Lee, 1951; Eyring, Christensen, *et al.* 1948; Lyman, 1948; Tucker, 1951; Marshall, ; Trout, Lee, Richardson and Harden Jones, 1952; Hersey *et al.*, 1952; Tchernia, 1952).

2. PREVIOUS WORK

ıere is a great effort in industry and research concerned with the results of echo sounding. In ıis work, there is a fundamental lack; very little is known about the relation of the fish in the ɔ the mark on the trace. This is complex and will be considered in stages. The various trace arances will be described and their relation to the size of shoal established. It will be shown four factors—the presence or absence of air bladder, the frequency of sound used, the shoaling ity of the fish, and the size of shoal relative to the cone of sound—affect the appearance of a ;. The limits to identification will be discussed.

ı the relation between the wave front of sound and the fish shoals, there are two sets of papers ɔse on the identification of fish by the echo sounder, and those on the survey of fish abundance ɛa.

1947, Renou and Tchernia published echograms of pilchard, herring, sprat, and *Thynnus ɪnga;* three types of herring trace were distinguished. Hodgson (1950) was the first to show

that different species had a different appearance on the echo trace; he was able to distingu herring, sprat, pilchard, mackerel, and gadoids from a ship that was usually stopped. Schub (1950*c*) has published traces of tunny on the Fladen Ground. Sund (1935) and Kristensen (19 have published echograms of cod spawning at Lofoten. These sometimes have the spotty chara noted by Hodgson for gadoids, and sometimes have the shaded layered character of spawn herring (*cf.* Renou and Tchernia, herring type 2). Krefft and Schüler (1951*b*) showed that as darkr falls, the shape of the herring trace changes from a compact one to an irregular diffuse one as shoal climbs into the mid-water. Tchernia (personal communication) has found that cap shoals off Newfoundland take up the well-known comet appearance, as do cod off Iceland in 170 Schärfe (1951) has shown records of perch and *Coregonus wartmanni* in the Bodensee; echogram squid were published by Mishima (1951). Examination of all these records shows that fish sh can give rise to four types of trace:

(1) The small spot due to gadoids (Hodgson and Sund), that is also characteristic of *Corego* This spot trace can be extended to a stumpy comet if a machine with a very fast paper sp is used.

(2) The comet appearance due to sprats (Hodgson, Richardson), that is also characteristic capelin and cod in much deeper waters. This trace may be produced by a shoal tha considerably smaller than the section of the cone of sound at the depth of observati obviously, the " gadoid " spot is much smaller still.

(3) The compact deep mark with a diffuse edge due to herring, that is characteristic also mackerel (de Boer) and summer pilchard shoals (which have been seen in the Chan D.H.C.). In the autumn, the pilchard shoals take on the sharp black edge, noted by Hodg These traces may be produced by shoals that are wider than the sound cone at the de of observation; they are also considerably deeper.

(4) The aggregated and irregular layer due to spawning herring (Renou and Tchernia, 1 that is also characteristic of 10 cm. herring and capelin in the Barents Sea (R. J. H. Bever personal communication).

It is interesting that all four types are displayed by Marchena (1951) as characteristic of sardine at different stages. It is a corollary to this observation that comet-shaped shoals on bottom of the Ratzeburger-See have yielded catches of perch, pike, carp, and roach (Schärfe, 19 Although it is clear that there is a limit to the rigorous identification of fish with the echo soun Hodgson's criteria are successfully in use among certain skippers to distinguish herring pilchards during the East Anglian fishery; Skipper George Leslie tells us that he is able to di guish pilchard traces by their hard edges. These criteria have also been successfully used Richardson (1950, 1951) to distinguish sprat and herring concentrations. Thus, they are us within the limits of a known fishery; cod in 170 fm., capelin and *Coregonus* produce comet-sh traces, but these fish are not found at the same place, nor at the same time as sprats. The evidently scope for a considerable study, to find what produces the characters of a trace.

There are a number of factors that might be concerned in the appearance of different fish sp on the echo trace; one factor of importance is the presence or absence of an air bladder. thinnest of all the echo traces is the mackerel's; Fig. 18 in Hodgson (1950) was taken on fish were shoaling tightly underneath the ship as they sheltered from the sun—yet the trace is on faint one. Because an echo is the result of a sharp change in impedance, it may be significant mackerel have no air bladders.

There has been no evidence published yet about the effects of different frequencies on the app ances of fish traces. One of the results in this paper will show that this is possibly a r important effect.

The third factor is the size of the shoals in the water. Hodgson's criterion for the identifica of sprats is that the trace on the paper has the appearance of a comet. This means that at the d of the shoal, the shoal occupies only a small part of the cone of sound and that the " path leng or apparent depth at first shortens and then lengthens due to the movement of ship and shoal rela to each other (see Fig. 1). In other words, the first signal at the deeper outer part of the com picked up from the edge of the cone of sound at the depth of the shoal. The traces of her

ard or mackerel, all of considerable extent in depth and width, may be larger than the cross-onal area of the cone of sound. Thus a comet-shaped trace is one that is given by a shoal is small in relation to the cone of sound; clearly, the cod shoal, giving a trace like a comet in m., might well present a different appearance in shallower water, even if the size of the shoal ot change.

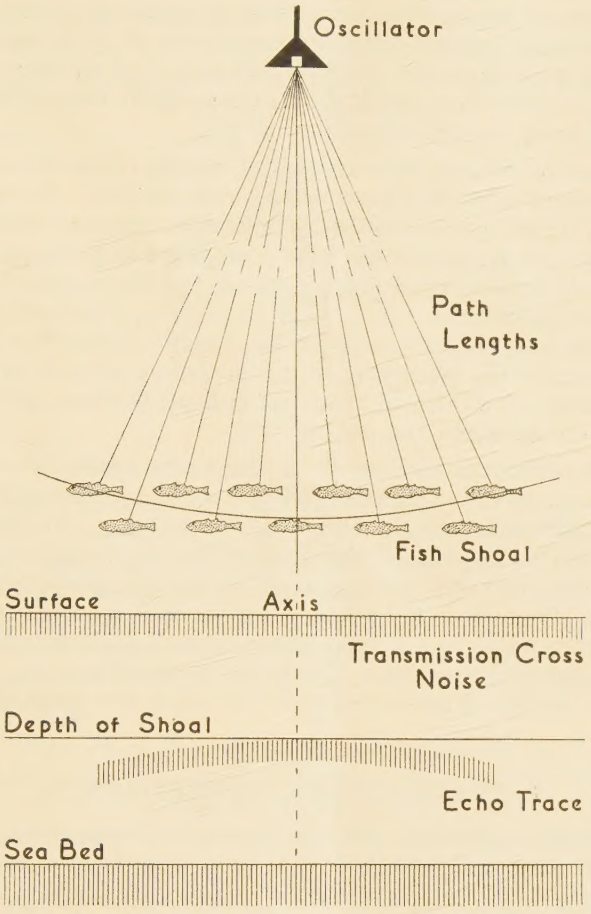


FIG. 1. The comet-shaped trace and its relation to the cone of sound. The trace is exaggerated horizontally in order to show the way in which it is made. A path length is the apparent depth of any part of the fish shoal that is moving across the sound beam.

fourth factor is the shoaling density of the fish. A signal of a given strength may be caused large number of small fish or a small number of large fish. There is no way out of this dilemma ; present commercial equipment. Fishermen often say that the pilchard shoals are more ly packed than the herring; the pilchard is a bit smaller in size, but Hodgson has pointed out the traces of pilchards are often blacker than those from herring. In other words a stronger l is being received from a smaller fish, so presumably, the fishermen's contention that pilchards more tightly than herring is true.

e may summarize by saying that to meet the requirements of driftermen, ringnetters, purse-rs, pelagic trawlers, and research workers, methods of echo-sounder identification must take t of four factors: the presence and the volume and shape of the air bladder relative to the ne of the fish; the size of the fish in relation to the *wavelength* of the sound; the shoaling ty of the fish; and the extent of the shoal relative to that of the cone of sound.

e second set of papers dealing with the relation of fish in the sea to the mark on the echo paper t concerned with echo survey. Runnström (1941), Sund (1943), and Kristensen (1950) have n that it is possible to make an estimate of herring density along a line of search; a similar

estimate was made by Tester (1943), and recently an estimate of North Sea herring concentrati was made by Krefft and Schüler (1951*a*) in this way.

Another method that has been in use since 1948, is that due to Cushing (1952); a relation has b found between echo units and the distribution of herring as shown by drifter landings, the dis bution of pilchards as shown by pilchard eggs, and the distribution of herring that aggregate o *Calanus* patches. The essence of this method is that each sounding is examined for the presenc absence of fish, and the results are combined as numbers of soundings on fish in the area. Richard (1950, 1951) used an analogous method to find concentrations of sprat and herring in the South Bight. From this work it has appeared that the " sampling " of an echo sounder could be re on for survey purposes, a point about which doubts were initially entertained, owing to differen in machines and to the many suspected unknown factors.

Richardson's identification of each trace as sprat or herring on survey was tested by the us sprat landings; Parrish and Craig (1952) have used a similar method. We have seen that the dif ent appearances of fish traces may be caused by differences between species or by difference behaviour within one species. When each fish trace is identified as belonging to a particular spec two different records could be interpreted as being caused by different species or being caused by same species behaving in two different ways. Thus, in a survey, a measure of abundance of a gi species is likely to be an under-estimate because the records taken when the fish were behav differently will be excluded. The alternative to this procedure is to assume that all records w made by the one fish species; this will lead to an over-estimate of abundance. The appropriate of use depends entirely on the region and season.

Areas of probable abundance can be charted, but there is no means of estimating how many there are in such areas. At the moment, one mark of the stylus means little more than the pres of fish, so the survey is built up on this presence and absence basis. Variation in power outpu water conditions, in amplifier linearity, in the speed of the paper and its moistness are cause large errors. This is before we know anything about the acoustic properties of the fish themsel or of their distribution. We need to know how much sound is reflected by fishes; if one or n fish can be recorded acoustically; and if there is any relation at all between numbers of fish the quantity of sound received from them. The success of the echo survey methods rather sug that there must be some relation of this sort, even if it is only a very rough one.

3. PRELIMINARY EXPERIMENTS

A number of experiments concerned with the quantity of sound received from objects h beneath an echo sounder have been published. These are summarized as follows:

Sund (1943) had shown that echoes from 12 glass floats hung beneath an echo sounder w recorded down to 50 m. In 1950, Schnakenbeck reported that echoes from 40, 20, and 10 k live fish could be recorded; 7·8 kg. was the minimum weight to give an echo. Schärfe (1951) p lished records of an iron tube and some stones. Von Brandt and Schärfe (1950) have shown models of fish give echoes and that " shoals " of models or single models could be discrimin to the limit of the pulse length of the sounder. Schärfe (1952) has published polar diagrams of he has also tried to make a measure of colour intensity of trace for different objects. The t and one of the most interesting papers on the analysis of fish echoes, is that by Kimura (19 200 kc. sound was transmitted horizontally in a small pond containing fish and fry. Oscillogra records show that the received signal was clearly augmented by reflection from fish. These exp ments showed that the method of hanging fish beneath an echo sounder should yield profit results.

The first experiments that were carried out by the Ministry were exploratory—by testing diffe frequencies on the same shoal of fish at the same time. The apparatus consisted of two e sounders mounted alongside each other on the R. V. SIR LANCELOT. One was a **14 kc.** MS. 24 a 1500 v. contactor box, transmitting into the sea through an $\frac{1}{8}$ in. plate; the other was a 30 instrument with an 800 v. contactor box, transmitting through a $\frac{1}{16}$ in. plate. It is probable the power output of these two machines is roughly comparable, the main difference between t being the frequency. The beam angles of the two instruments were the same in these experim The performance of these machines was compared on herring shoals (and possibly sprats

is in December, 1949. A marked difference in results was found between sounders, yet the stical performances of the two machines were probably very similar. Comparisons were also e between 14 kc. and 30 kc. off Shetland, and between 10 kc. and 14 kc. and between 10 kc. and c. in the Barents Sea.

TABLE I

Numbers of soundings on fish and mean widths of shoals at different frequencies, comparing 14 kc. and 30 kc., 14 kc. and 10 kc. (30 kc/14 kc. : (*a*) all observations, (*b*) one set excluded because the amplifier gain on the 30 kc. was not set to the limit of the signal/noise ratio).

		Numbers of soundings on fish		*Mean widths of shoals in soundings*
		(a)	(b)	
f Calais 20 fms.	14 *kc.*	1906	1316	10, 6, 3, 1, 1, 2·5, 2·2, 3·0.
	30 *kc.*	2610	2220	9·5, 4, 2, 1, 1, 2, 1·5, 2·5.
rents Sea 100 fms.	14 *kc.*	54·2		3·0
	10 *kc.*	119·9		3·7

ble I shows the results of some comparisons. The strips of recording paper were laid out hat they were exactly comparable in time; thus the traces of the same shoal at the two uencies could be compared directly. The number of soundings on fish for each frequency the comparable periods was counted (by the method described in Cushing, 1952), and the mean ber of soundings on fish per shoal was estimated. The first comparison, between 14 kc. and c., was carried out on the herring shoals between Deal and Cap Gris Nez in December, 1949, there were three conditions under which this was done : (1) ship anchored; (2) ship drifting; hip steaming at full speed.

ie fish were not identified, although the majority of the shoals were probably herring. The chief lusion to be drawn from this comparison is that there was a marked difference in the number of dings on fish recorded, the 30 kc. machine recording nearly twice as many as the 14 kc. sounder. other conclusion is that the shoals recorded by the 30 kc. machine were, in general, smaller. second comparison was made between a 14 kc. machine and a 10 kc. machine in the Barents Sea ctober on fish that were probably cod. In this case the number of soundings on fish recorded he 10 kc. machine was the greater, and also the mean size of shoal was the greater. In both parisons, identification was made from the general fact that herring and cod were caught preinantly in the respective areas. This is not a satisfactory form of identification for this type of , but it is quite clear that differences in frequency give marked differences in the quantity of recorded, according to type of fish.

ie first result, that different frequencies gave different results, was the basis for rather more rolled experiments that were carried out in Windermere in 1950. We wanted to know if the of the fish bore any relation to the wavelength of the sound pulse, and if there was any relation een numbers of fish of the same size and the amplitude of the received signal. The main irement was that we should be able to hang fish below an echo sounder and that they should not out of the sound beams in a tidal current. This would be possible in Windermere where, by courtesy of the Freshwater Biological Association, we could work from anchored pontoons in it 35 fathoms of water.

4. OBJECTS USED AND MECHANICAL ARRANGEMENTS

ie objects used in this series of experiments were fish and artificial air bladders. The fish that used were cod and herring. Fifty cod within the size range 24–30 in. were obtained for us by G. M. Buchanan-Wollaston, then Fishery Officer, Fleetwood. Half a cran of herring were

obtained from Shields. All fish that were used in the experiments were carefully gutted and fi in formalin. The air bladders were artificial rubber balloons the volumes of each of which w

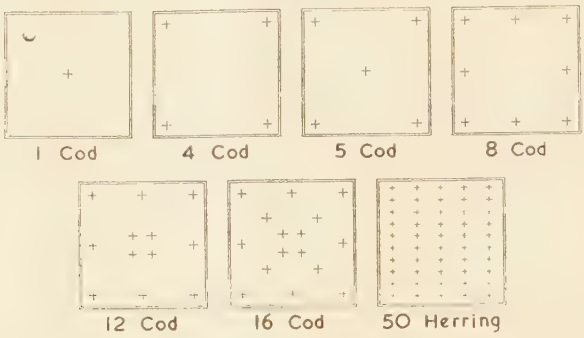


FIG. 2. The patterns of fish on the frame.

adjusted to that required and then the balloon was sealed off with rubber solution. These w used with the cod, and their volume was always adjusted to 110 ml.—which was 5 per cent. of mean volume of the cod used (Taylor, 1922; Jones, 1951). Cod, cod air bladders, and her were arranged as in Fig. 2.

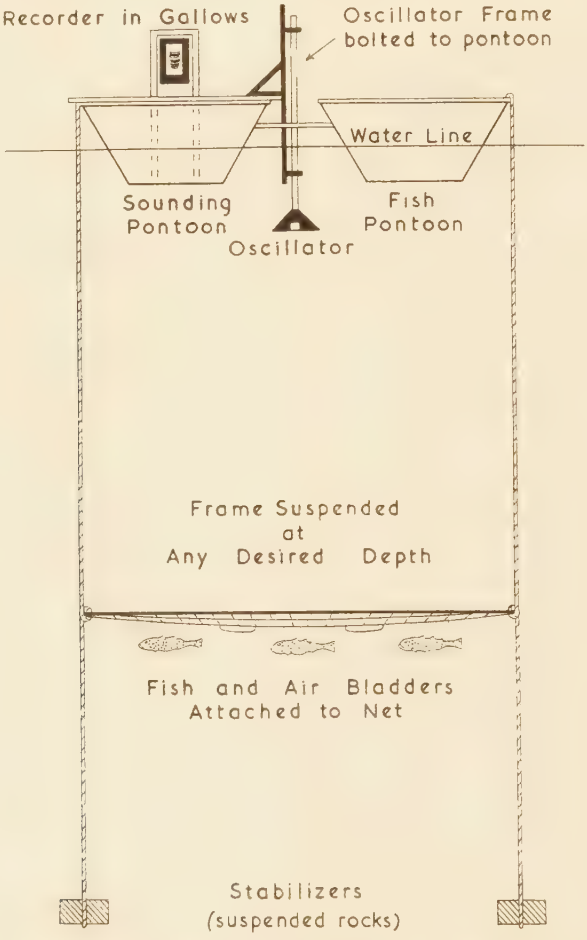


FIG. 3. The arrangement of the pontoons and frame in depth.

Attached to the centre buoy on Windermere we had two pontoons lashed together side by one contained all the sounding equipment and the other the fish (Fig. 3). The dead fish (witl air bladders separately) were to be hung in their swimming positions on netting stretched acr

re frame that was hung by its corners from the pontoons. The frame was operated from the pontoon and suspended from the four corners of the double pontoon by ropes. This frame made of aluminium tubing with many holes in to allow it to quickly fill with water. It was et square, suspended at the four corners by the pontoon ropes and weighted at these four ers with rocks on further lengths of rope—about 12 feet. Netting was spread across the e; from this were hung the dead fish and separately from them, their artificial air bladders.

fore use, the frame was placed upside down across the fish pontoon and the starboard ropes the pontoon were brought underneath the frame and attached to its port side; the port ropes the pontoon were brought underneath the double pontoon and attached to the starboard side e frame. Then the frame could be lowered over the side so that it would take up the right ion underneath the two pontoons. When fish were being attached to the netting, they were put on in the starboard positions, and that part of the contraption was lowered into the water. was held vertically and more fish were attached and so on until the frame was full and com- ly immersed. Observations were made after the frame had been lowered to 30 fathoms mospheres) to eliminate air bubbles.

hen the frame was lowered over the side, it was first drawn up underneath the pontoon to make in that it had arrived the right way up, that it was horizontal, and that the fish were still attached. it could be lowered to the observation depth. The suspending ropes were marked in fathoms tat the frame could be lowered to various depths and would remain horizontal. Sometimes vind would change slightly and blow the pontoons away from their earlier position; when this ened the ropes were no longer vertical and we waited until they were.

sadvantages in this form of arrangement were that the speed of sound is different in fresh water that in salt water, that the fish used were dead and full of formalin and that we did not know hoaling density in nature of any of the fish with which we were dealing. The air bladders were separately from the fish; this is a further source of error because the fish/air bladder interface oe, for sound waves, slightly less sharp than the water/air bladder one.

5. SOUNDING EQUIPMENT

e sounding equipment was designed by Mr. Halliday and Mr. Sparling of Messrs. Kelvin and ies. It consisted of three echo sounders using one contactor box and one recorder. The three ders were of three frequencies (10, 14, and 30 kc.); the oscillators were of the magneto-strictive iated ring type. Their reflectors were of such dimensions as to produce identical beam angles, n be seen from the directionality diagrams (Fig. 8). The oscillators were screwed into 5-ft. which were clamped on to iron holders, which were in turn screwed to timber lashed to the oon. A 1,000 volt contactor box produced the pulse for the transmitters, and a three-stage ifier, tuned to the appropriate frequency, amplified the received signal for the paper recording. recorder was carried on a special gallows, loaned by the Freshwater Biological Association. is arranged to trigger the time base of a Cathode Ray Oscilloscope (Cossor 3335), and the l was led into the Cathode Ray Oscilloscope directly from the receiver. Associated with this an Admiralty pattern signal injector.

ere were two power systems in use. We used a double bank of four 12-volt batteries, one on charge while the other was in use. The input to the rotary converter which served the ifier and contactor box was 24 volts, and the same voltage was used to drive the recorder. A lt rotary converter was used to operate the Cathode Ray Oscilloscope, but after a short time vas found to be unsatisfactory and was replaced by an A.C. cable supplying a 100 cycles/sec. nt from shore supply to the oscilloscope. The charging of the batteries was carried out .

e pontoon arrangement is shown in Fig. 4. The frontispiece shows the equipment, as arranged. oasis of this arrangement was that the signal from the receiver going through a potentiometer wo channels: the usual channel of the three-stage amplifier and the recorder; and through the ifier to the Cathode Ray Oscilloscope with a signal injector tapped in. This was to enable eceived signal to be measured independently of the amplifier of the echo sounder; the received l could then be matched on the oscilloscope—under the same conditions—with the injected l, of which the magnitude was known. The actual gain of the Cathode Ray Oscilloscope

amplifier did not therefore enter into the measurement. The linearity of the Cathode Ray Oscil scope amplifier could be checked at any moment by using the injected signal on the screen. the signal injector produced signals at intervals of magnitude of $\sqrt{2}$ μv., the injected signals w

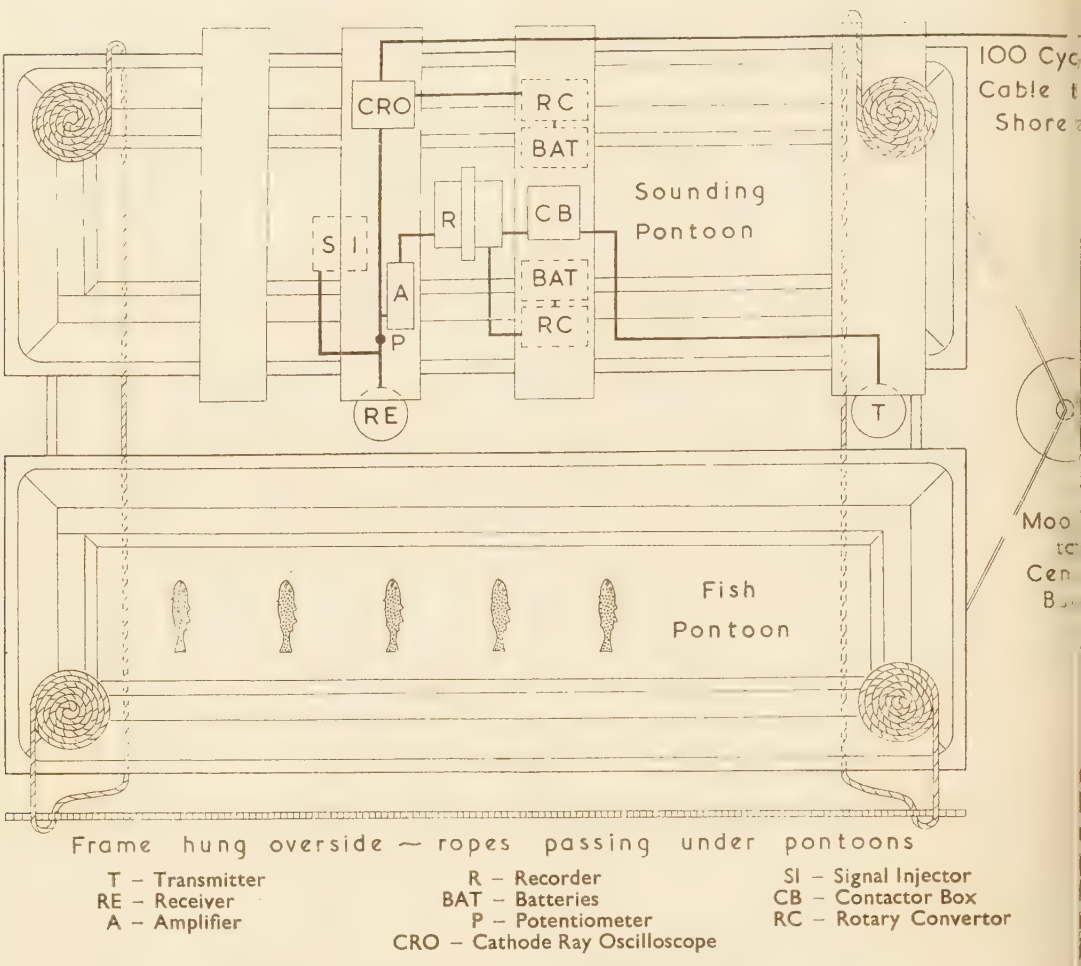


FIG. 4. The arrangement of pontoons and sounding equipment from above.

expected to appear following this law. If the amplifier became overloaded by the received sig signals of increasing magnitude from the injector showed constant amplitude on the screen; the potentiometer was used to cut down the received signal until the amplifier was no lo overloaded.

6. PROCEDURE

Measurement of the received signal was carried out in the following way: with the rece signal on the oscilloscope screen the injected signals were checked for the amplifier's linea Then the received signal was examined for about a minute to make sure that the system had bec "steady." The job was separated so as to be worked by two persons—a screen observer a signal injector operator. The screen observer matched the injected signal with the received si on the screen and the signal injector operator recorded the quantity of the injected signal, watch on the whole system with the recorder, and checked linearity with the potentiometer. N important of all, he controlled the screen observer and made him read and repeat the readings consistency had been obtained; the reason for this procedure was that the screen observer c not see the dial of the signal injector. The measurement of the signal was complete when t consecutive readings were consistent. The three or more peaks of the signal were measured

itude separately. The length of each peak along the time base was recorded, and lastly a check made on the linearity of the amplifier.

iginally we standardized our signals on a steel plate at 7 fathoms; when we found that a tion of a very small angle from the horizontal plane produced a great change in signal strength, bandoned the use of the plate and used the frame itself. It would have been preferable to use a steel ball. Although these checks on the variability of the system were not as complete as they l have been, we felt that they were adequate at the present stage in the investigation.

7. THE RECEIVED SIGNALS

e signals that we received were not simple peaks. When we sounded on the steel plate, the l received on the screen was a very narrow one with a single peak. When sounding on the e and fish we always received a complex signal. The system on which we were sounding is n in Fig. 3 (p. 6). The received signal could be composed of components from the frame, opes, the net, and the fish. The rocks could be distinguished quite easily from the other es because they hung about 12 ft. below (Fig. 5). The frame, net, and ropes gave quite a sh signal and this might well be due to the sum of echo lengths from different parts of the m, e.g., there might be some small reflections from the net, a stronger one from the frame, and

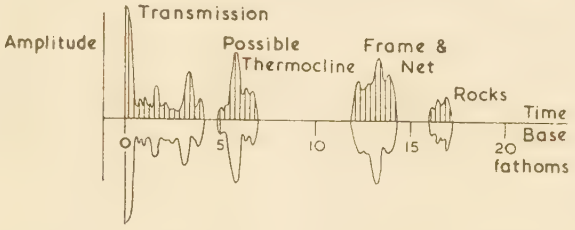


FIG. 5. Types of signals as they appeared on the oscilloscope.

small ones from the bits of rope; the frame alone did give this sort of echo, but we would not o assert that we have interpreted this complex signal quite correctly. The fish and frame echo a very long one, the length of which increased roughly with the numbers of fish. There are two ible explanations of this. The first is that the sound might reverberate between fish before g returned to the receiver. Theoretically this must take place, but whether it is measurable is her question; if so, one would expect that the signal amplitude should decrease along the time —which it did not. The second possible explanation is that the weight of fish made the net and, as the length of echo increased with the number of fish, this is quite plausible—although nt reasons will be given in the next section for rejecting this explanation. It should be pointed hat this effect has no relation to the " tail " of paper records of fish shoals, which might be due idely diverging path lengths from an extended fish shoal.

was often suggested to us that we should hang the fish on strings from the frame, long enough ake the fish echoes quite distinct from the frame echoes. This is the best solution when dealing numbers up to half a dozen fish, but beyond that number we found that the strings became led. Therefore it seemed that the only practicable method, at the moment, was to estimate overall amplitude and subtract from it that due to the frame. We did compare the signal gth from a few fish hung below the frame with that from the same number on the frame. The rence between them did correspond to the signal strength usually received from the frame. her point is that fish arranged in a horizontal plane are bound to give a complex echo if the of the plane is large enough, because of the different path lengths (distance from object to ver, however far the object may be from the axis of the receiver); if there is such a complex in any case, the virtue of using individual fish is lost.

nong the signals, there was an interesting difference between frequencies. Sounding on fish frame, there were usually three peaks within a particular signal. These peaks were often of rent amplitudes, and at a particular depth were usually constant in arrangement; but if the h was changed, the order of amplitudes along the time base might also change. The only r that seems to be relevant is that as the depth increases, the frame subtends a smaller angle at the

receiver. This suggests that differences in path length due to the angle subtended at the recei by the frame, become reduced, and differences due to reflectivity of different parts of the syst assert themselves more markedly, because of changes in acoustical aspect. The difference betw

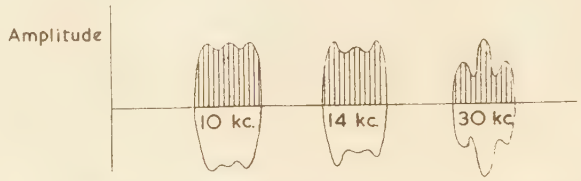


FIG. 6. Diagrammatic differences in signals between frequencies.

frequencies is illustrated in Fig. 6. The three peaks were only just noticeable using 10 kc., but w extremely marked when using 30 kc.; the picture from 14 kc. represented an intermediate positi The pulse length (1 ms.) was about the same for the three frequencies: we can find no explanat for this phenomenon.

When the frame was lowered to the depth of observation, we noticed that echoes from the rc were recorded and that the system often took a long time to "settle down". This was partly to the frame being lowered or lifted unevenly, and perhaps partly due to the vibration of the rc themselves. This is supported by the observation that a trawl used pelagically introduced a g deal of noise on the echo sounder (personal communication from R. J. H. Beverton).

At certain depths at certain times we observed fairly constant signals—usually at about 5 fath or about 24 fathoms; the signal at 5 fathoms was a sharp noise, later associated with a thermoc whereas that at 24 fathoms was spread diffusely over about 3 fathoms; we had neither the time the appropriate equipment to analyse this "mush". The fact that it did not change its de

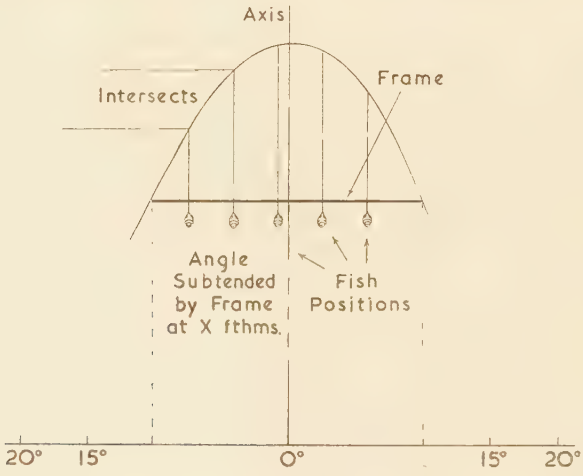


FIG. 7. The use of a directionality diagram to correct for the effect of beam angle.

under widely varying light conditions (up to 2100 hours G.M.T.) does not necessarily preclu biological character; Windermere is not a clear lake (Pearsall and Ullyott, 1934), and Worthin (1931) has shown that it is possible for a secondary zoo-plankton population not to mig diurnally. However, animal plankton is quite dense in Windermere and with our instrument saw nothing that performed a vertical migration as animals do in this lake (Ullyott, 1939).

When the equipment was first assembled on the pontoon, the oscillators were placed quite c together. This produced a heavy cross noise and we had to shift them until they were 5 ft. ap In the original arrangement, it had been intended to place both the transmitter and the rec centrally over the area of the frame. This cross noise meant that the receiver was placed in centre, but that the transmitter was placed over the edge of the frame. Now, the oscillators l polar diagrams that are similar. In this arrangement, the directivity patterns of sound bec

ted and the sound transmitted to different parts of the frame would be very different at w depths. Conversely, at 8 or certainly 12 fathoms, the frame is fairly near to the axis of mbined directivity pattern; the arrangement was not entirely satisfactory as the axis of the ned pattern was slightly off the centre of the frame.

ociated with this problem is the effect of the width of the frame in the received cone of sound. fathom the envelopes of sound cover only small parts of the area of the frame. At 8 fathoms ole of the frame was easily within the received envelope of sound, but only the centre of it was axis. The amplitude of received sound at a given depth, in this context, depends on the

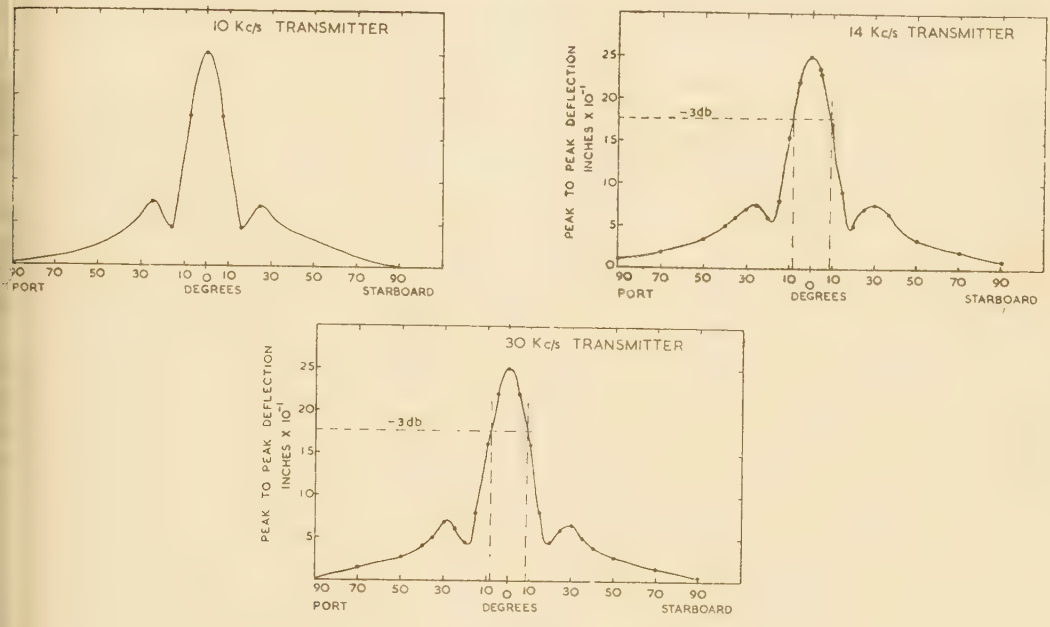


FIG. 8. Directionality diagrams for the three transmitters.

ir departure of the " path length " from the axis. The right procedure would be to integrate rve of sound distribution within the angles subtended by the frame at particular depths. An procedure was to use the directionality diagram in the following way: at a given depth the subtended a given angle and this was fitted into the directionality diagram. At the various ositions on the frame from the side view, perpendiculars were drawn to the curve above. cut the curve, and the ratio of this intersect to the axis intersect constituted a multiplier (see . Multipliers for each position were estimated, squared, and averaged to make an " integral " by which the signal amplitudes at the different depths were multiplied. These factors were Beam Angle Multipliers. Only the transmitter directivity patterns were used. These are in Fig. 8.

8. TREATMENT OF RESULTS

ing the experiments, it became clear that the duration of the received signal varied greatly iat this variation was probably related to numbers of fish. Table III (pp. 18–19) shows the al observations as amplitude, the height of a peak on the oscillogram, and, as duration, the of this peak. The relation between duration of signal and numbers of objects is shown in . This is a marked regression. The five points on the ordinate for any one number of fish abscissa, are the observations at the five depths. Examination of Table III will show that rations are smaller at greater depths; the degree of this trend is the same for all numbers, so easonable to treat all observations as contributing to one regression. It was at first thought iis regression was caused by the sagging of the net with increased numbers. If this were so, t would have to sag between 4 and 6 ft., which it certainly did not do. Again, the regression arent with low numbers, where no sagging at all should be expected. This point becomes

much more cogent when it is realized that the sagging due to one cod must be greater than that to four cod, because the four are at the edge of the net and the one is in the centre (see Fig. p. 6).

The relation shown in Fig. 9 confirms the impression that the signal was a complex one and the first amplitude was not necessarily the relevant part of it. It was decided to measure the ar tude of each peak and also its duration along the time base. Then the amplitude of each peak multiplied by its duration along the time base, to make a measure of *Amplitude* × *time*.

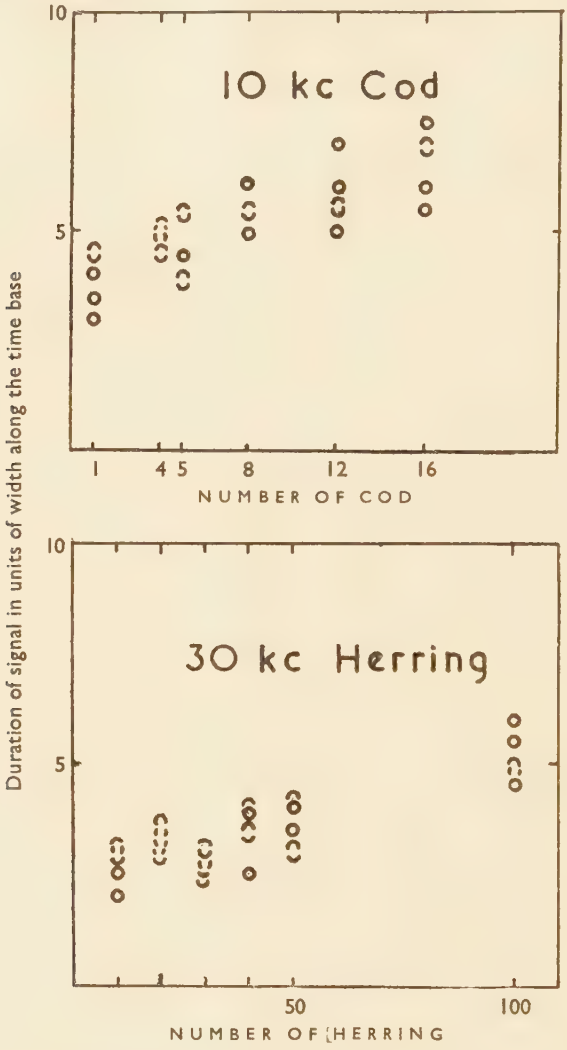


FIG. 9. The relation between the duration of signal (as measured along the time base) and numbers of cod or herring.

method, the method of measuring the area of the complex signal on the oscilloscope, integrate signals from the whole system of frame, net and fish.

The observations, expressed as *Amplitude* × *time*, were treated in two ways. The first w attempt to estimate the signal from one object, in order to compare it with that from other ob at the three frequencies; the estimates so derived were called " comparable signals ". The se was an attempt to estimate the relation between the values of *Amplitude* × *time* and depth, in to find the slope of regression between these two variables. The two methods are set o Table II (pp. 14–15).

That part of the table concerned with Method I is divided into two sections : the derivati " signal strength ", and the derivation of " comparable signal ". The estimate of signal str

estimate of the received signal from a given number of objects, that has been corrected for and the spread of beam angle. In order to do this, the values of *Amplitude* × *time* due to the have been fitted to a regression on depth. Then the smoothed values due to the frame have itted to a regression on depth. Then the smoothed values due to the frame have been sub-d from the *Amplitude* × *time* signals due to any object.

B. C. Browne has pointed out to us that the method of subtracting the *Amplitude* × *time* the frame from those due to the frame and fish, is valid only if the frame with the fish sus-d from it are exactly in phase with each other, with respect to the sound waves. As this is ly, a more proper method would have been to consider the energy relationships of the system; eans that the amplitudes should be squared before they are multiplied by their duration. Thus d of *Total Amplitude* × *time* − *Frame Amplitude* × *time* we have

$$\sqrt{\textit{Total Amplitude}^2 \times \textit{time} - \textit{Frame Amplitude}^2 \times \textit{time}}.$$

quare root of the difference is extracted at the end of the operation (see Table IVa on p. 21).

s procedure was carried out on two sets of results, the 30 kc. cod and the 10 kc. herring. It rried through to the second part of Method I, the derivation of comparable signals. It will own in Table IVa that for these two sets of results, there is a marked decline of com-e signal with depth. This trend is preserved when the results are treated by the correct proce-$\sqrt{\textit{Total Amplitude}^2 \times \textit{time} - \textit{Frame Amplitude}^2 \times \textit{time}}$. Hence it was assumed that the al method could be used within certain limits.

en the frame value was subtracted from total *Amplitude* × *time* value, the remainder was lied by the square of the depth. The sound energy reaching a surface distant from the nitter is inversely proportional to the square of that distance. As intensity varies as the square amplitude, the amplitude measured at the receiver would be inversely proportional to the of the distance of the object. Consequently, when the *Amplitude* × *time* values at each were multiplied by the square of the depth, they should then be at about the same value. So pression *Total Amplitude* × *time* − *Frame Amplitude* × *time* was multiplied by the square of the ; the expression was also corrected for the decrease in intensity of amplitude across the area frame, due to the directionality of the oscillators, with the use of Beam Angle Multipliers as ed in Section 7. The final expression, obtained in this way, is called " signal strength ".

second part of Method I shows how the comparable signals were derived. Signal strengths 10 kc. cod series are shown as part of the table. Regressions of signal strength on numbers alculated for each depth series. The purpose of this procedure was to find the mean signal th from a mean number of objects at one depth. From this expression a measure of the signal th from one object could be obtained. The intention was to use as many observations as le and to extract the maximum amount of information from them.

h comparable signal so derived was divided by the calibration value for each frequency, given . These comparable signals must have some expression of error attached to them. This sion is shown in Table II. Thus the standard error of the mean estimated signal strength the mean number of objects will be $\sigma \sqrt{\frac{1}{n}}$. In order to compare this error between ie expression $\frac{\sigma \sqrt{1 + \frac{1}{n}}\, 100}{\bar{y}}$ was used; this is analogous to the coefficient of variation and the same purpose. There was no trend of error with the sets of observations used; the varied between 13·72 and 89·86 per cent. The errors attached to the comparable signals erived in the same way as that value itself.

first method of dealing with the observations was concerned with comparing the magnitude al returned from different objects at different frequencies at each depth. The second method erned with the way in which the received signal varies with depth. Theoretically, as stated the received signal varies inversely with the square of the depth. Inspection of results ed by the comparable signal method suggests that this assumption may not apply. There ssibility that the deviation from the inverse square relation may be a consequence of the d used of subtracting the " frame " values. Regressions were made of log *Amplitude* × *time* ; depth for each set of numbers of each object; from these, slopes were obtained and were red. Estimates were derived, subtracting the regression of frame on depth from that of

Amplitude × *time* on depth; these yielded the same type of result. Thus, in the second method, values due to the frame were included in the derived expression. Table II shows the slopes obtai for the 10 kc. cod series and also the standard errors to be attached to these slopes; in this serie appears that the error increases with increasing numbers.

TABLE II

Treatment of Results

Method I. Derivation of " signal strength "

Example : 10 *kc. cod*

Depth (fms.)	12	16	20	24	28
8 *cod amplitude* (*μ.v.*) (*time*)	125 (5·5)	88·4 (6)	22·1 (0·5) 88·4 (5·5)	22·1 (0·5) 62·5 (5)	31·2 (2·5) 44· (2·
Amplitude × *time*	687·5	530·4	497·2	323·5	188·6
Frame (*Amplitude* × *time*)	268·5	122·2	98·8	29·8	18·8
Signal strength	140,262	150,761	230,148	201,887	154,279
Beam angle multipliers used : (for 8 cod) (B.A.M.).	2·41	1·49	1·35	1·23	1·17

Signal strength for series 10 *kc. cod*

Fms. / *n*	*12*	*16*	*20*	*24*	*28*
1	19,939	22,693	28,280	36,206	37,312
4	55,203	50,176	63,504	82,296	83,189
5	112,326	87,201	65,448	98,171	98,968
8	140,262	150,761	230,148	201,887	154,279
12	159,939	234,899	221,940	112,109	149,939
16	272,126	463,008	249,066	263,478	287,760

Derivation of estimate of error

	σ	n	$\bar{y}$	$\frac{\sigma\sqrt{1+\frac{1}{n}}\,100}{\bar{y}}$
12 *fms.*	24·7	6	126·62	21·07%

Derivation of comparable signal and error

Comparable signal $= \frac{\bar{y}}{\bar{x} \cdot c} = 1{\cdot}101$

Error of comparable signal $= \frac{\sigma \cdot \sqrt{\frac{1}{n}}}{\bar{x} \cdot c} = 0{\cdot}088$

Coefficient of variation $= \frac{\sigma\sqrt{1+\frac{1}{n}}}{\bar{y}}\,100 = 21{\cdot}07\%$

σ = standard deviation from regressio

$\bar{y}$ = mean " signal strength "

$\bar{x}$ = mean number of objects.

c = calibration value.

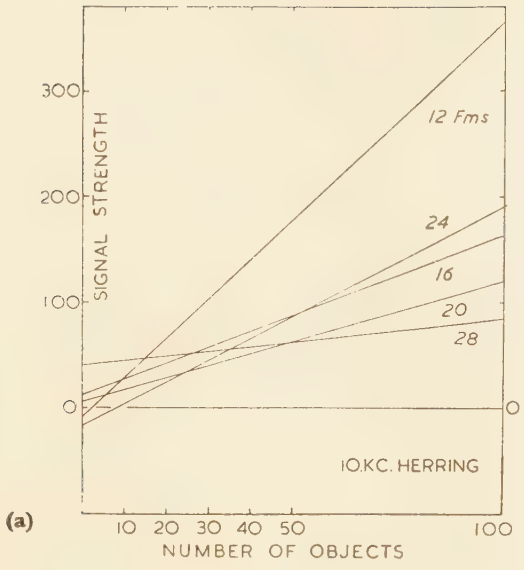
hod II. Derivation of A_1 for the series 10 kc. cod

d at 10 kc.

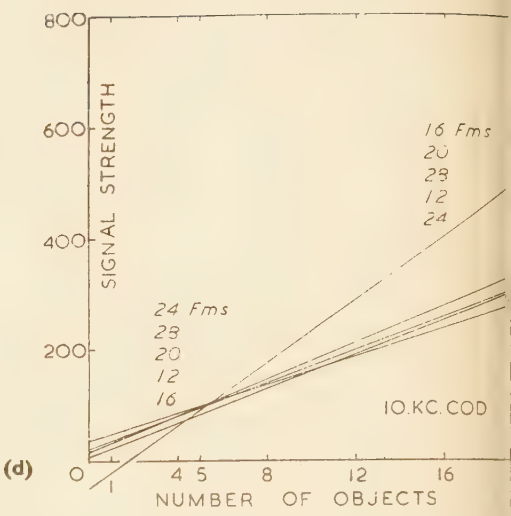
epth (fms.) ...	12	16	20	24	28
mplitude × time	687·5	530·4	497·2	323·5	188·6

$$Log\ (Amplitude \times time) = A_1\ log\ Depth + C$$

n	A_1	*Standard error of slope as fraction of slope*
1	2·1135	0·0211
4	1·5784	0·0397
5	2·2885	0·0672
8	1·4023	0·2370
12	1·8048	0·2863
16	1·5760	0·3041



(a)



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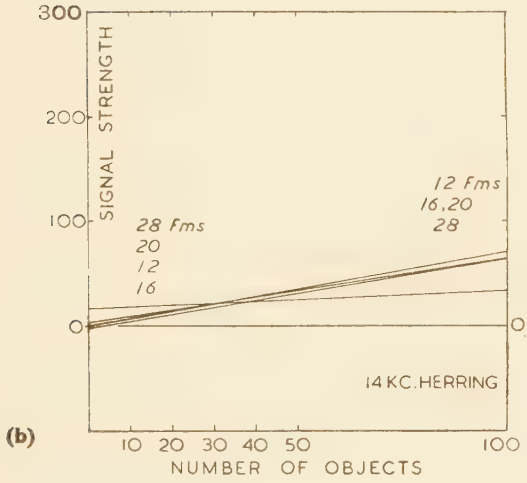
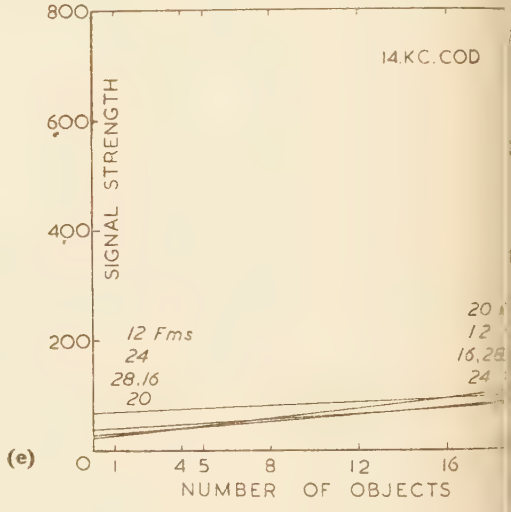


(b)



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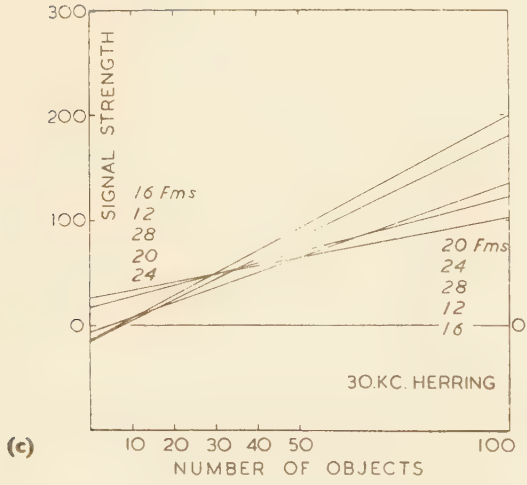

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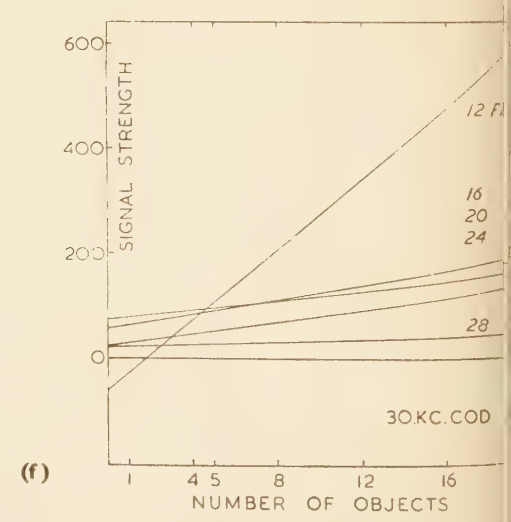
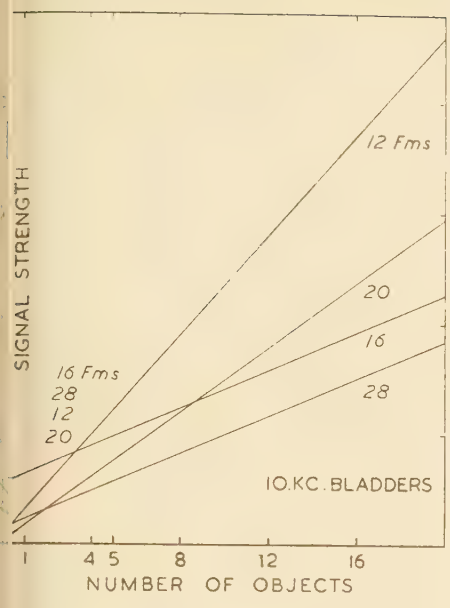
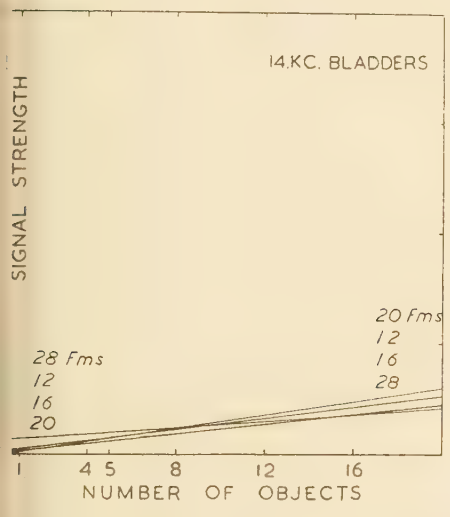
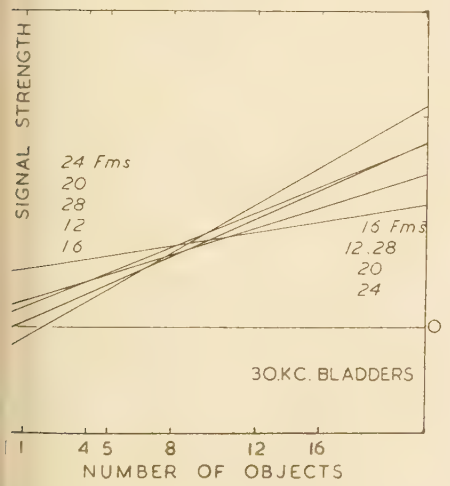


(f)

FIG. 10. Regressions of "signal strength" on numbers of cod, her







PART II

RESULTS

1. OBSERVATIONS AND PRINCIPAL RESULTS

THE original observations are given in Table III (pp. 18–19). Each signal consists of two or three peaks. The amplitude for each peak is given, and the duration of each peak along the time base in mm. is given. These results are given for the different objects, at the three frequencies and at various depths. By the procedure set out in Table II, these results have been converted to "signal strength". On examination, they showed with some exceptions in the 45 series a tendency for greater signal strength to be given by greater numbers of objects.

There was, however, considerable variation in the data, which has to be eliminated by the use of means and regressions of signal strength on numbers of objects as in Fig. 10. Whatever the precise form of the relationship between signal strength and number of objects, a proportional relation—linear and passing through the origin of the graphs—seemed in most of the 45 examples to give a reasonable representation of the trends. In practical terms this may be stated as "the greater the number of objects, the greater the signal strength". When the nine sets of regressions in Fig. 10 are compared (for each of three frequencies on each of three objects—cod, herring, and bladders), it is seen that at the intermediate frequency 14 kc. (Fig. 10b, e, h), signal strengths are distinctly less than those at the low frequency 10 kc. (Fig. 10a, d, g) or those at the high frequency 30 kc. (Fig. 10c, f, j). This phenomenon held for all three objects. This difference in the relationship between numbers and signal strength cannot be ascribed to differences in transmitted energy of the instruments, kindly worked out for us by Mr. Sparling of Kelvin and Hughes Ltd. The relative calibration figures are: 10 kc., 15; 14 kc., 8·8; 30 kc., 12: whereas the signal strength ratios between frequencies are many fold.

It is further to be observed in Fig. 10 that the regression lines for each depth of observation do not usually have the same slope, and in some (Fig. 10a, f, g) the relation between signal strength and number of objects increases most rapidly in one or other of the two shallower depths—12 or 16 fathoms.

Amplitudes in μV, for herrings, cod, and bladders at each depth and for each
impossible to estimate th

	12 fms.			16 fms.		
	1*st*	2*nd*	3*rd*	1*st*	2*nd*	
10 kc.						
Herrings						
10	125 (3)			88·4 (2·5)		
20	125 (2·5)			88·4 (2·5)		
30	353 (2·5)			125 (2)		
40	353 (3)			125 (2·5)		
50	500 (3·5)			250 (3)		
100	500 (4)			151 (4)		
Cod						
1	31·2 (1·5)	125 (3)		31·2 (1·5)	88·4 (2)	
4	88·4 (2·5)	88·4 (2·5)		44·2 (2·5)	62·5 (2·5)	
5	125 (5·5)			62·5 (2·5)	88·4 (3)	
8	125 (5·5)			88·4 (6)		
12	88·4 (3)	177 (4)		177 (6)		
16	177 (7·5)			250 (7)		
Bladder						
1	88·4 (3·5)			44·2 (3)		
4	125 (4·5)			88·4 (4)		
5	88·4 (4)			177 (3·5)		
8	106·7 (2)			106·7 (5)		
12	250 (5·5)			106·7 (5)		
16	250 (5·5)			125 (5·5)		
Frame Alone	22·1 (2·5)	44·2 (2)	62·5 (2)	31·2 (2·5)	22·1 (2)	
14 kc.						
Herrings						
10	7·8 (2)	31·2 (3·5)		22·1 (2)	15·6 (3)	
20	22·1 (1·5)	44 (1·5)	22·1 (1)	11 (1)	7·8 (1)	
30	44·2 (1·5)	15·6 (1·5)	44·2 (1·5)	22·1 (2)	15·6 (1)	
40	62·5 (3)	31·2 (2·5)		31·2 (2)	15·6 (2)	
50	88·4 (3)	44·2 (3)		15·6 (1)	44·2 (3)	
100	44·2 (2·5)	88·4 (2·5)	62·5 (2)	44·2 (3)	22·1 (2)	
Cod						
1	11·0 (1·5)	5·6 (1)		7·8(2)	3·9 (1)	
4	62·5 (4·5)	53·3 (2·5)		44·2 (3·5)	53·3 (2)	
5	31·2 (2)	88·4 (2·5)		22·1 (2)	44·2 (2)	
8	62·5 (3·5)	62·5 (3·5)	22·1 (2)	44·2 (2·5)	31·2 (1)	
12	44·2 (2)	62·5 (2·5)	62·5 (2·5)	26·6 (2)	44·2 (2)	
15	125 (2)	62·5 (1·5)	125 (2)	88·4 (2·5)	31·2 (2)	
Bladder						
1	22·1 (2)	11·0 (3)		15·6 (1)	11·0 (2·5)	
4	31·2 (3)	15·6 (2)		11·0 (2·5)	7·8 (2)	
5	44·2 (2)	15·6 (2·5)		22·1 (3·5)	11·0 (2)	
8	44·2 (1·5)	31·2 (2)	31·2 (2)	15·6 (1)	15·6 (1·5)	
12	62·5 (2)	15·6 (1)	31·2 (2)	22·1 (2)	15·6 (1)	
15	62·5 (2)	31·2 (2)	31·2 (2)	31·2 (2·5)	22·1 (2)	
Frame Alone	44·2 (2)			15·6 (1·5)		
30 kc.						
Herrings						
10	31·2 (1)	177 (1)	88·4 (1)	125 (2)		
20	88·4 (1)	125 (1)	62·5 (1)	31·2 (1)	62·5 (1·5)	
30	125 (3)			53·5 (1·5)	62·5 (1·5)	
40	88·4 (1)	177 (1·5)	353 (1)	44·2 (1)	125 (2)	
50	125 (2·5)	353 (1·5)		88·4 (2·5)	177 (1)	
100	88·4 (2·5)	177 (2)	125 (1·5)	177 (1·5)	75 (1·5)	
Cod						
1	125 (2)	250 (2)		125 (2)	62·5 (1)	
4	177 (2)	88·4 (1·5)	22·1 (1)	177 (2)	31·2 (1·5)	
5	106 (2·5)	177 (2)	62·5 (1·5)	88·4 (2·5)	62·5 (2·5)	
8	31·2 (1)	125 (2)	88·4 (2)	106·6 (2)	31·2 (1)	
12	88·4 (3)	250 (2)	62·5 (1)	44·2 (2)	125 (2)	
16	426 (8)			250 (2)	62·5 (5·5)	
Bladder						
1	22·1 (1)	44·2 (1·5)	44·2 (2·5)	31·2 (1)	44·2 (2·5)	
4	22·1 (2·5)	106·7 (3)		15·6 (1·5)	37·7 (2·5)	
5	53·3 (2)	31·2 (1·5)	88·4 (3·5)	22·1 (1·5)	62·5 (3)	
8	31·2 (2)	22·1 (2·5)	62·5 (2)	22·1 (2·5)	44·2 (2·5)	
12	62·5 (1)	177 (1·5)	353 (1)	88·4 (1·5)	62·5 (1)	
16	125 (3)	500 (1)		125 (3)	213 (1·5)	
Frame Alone	62·5 (1)	75·3 (1·5)	31·2 (1·5)	22·1 (0·5)	53·3 (1)	

f each signal is shown in brackets; at 24 fms. it was sometimes
cause of "mush".

20 fms.		24 fms.			28 fms.		
2nd	*3rd*	*1st*	*2nd*	*3rd*	*1st*	*2nd*	*3rd*
		31·2 (2)			22·1 (2)		
		44·2 (2)			31·2 (2)		
		44·2 (2)			44·2 (2)		
		62·5 (2)			44·2 (2·5)		
		62·5 (2·5)			62·5 (2·5)		
		88·4 (4)			31·2 (3)		
44·2 (2·5)		15·6 (1·5)	31·2 (2·5)		5·6 (1)	31·2 (2)	
44·2 (2·5)		22·1 (2)	44·2 (2·5)		15·6 (1)	22·1 (1·5)	31·2 (2)
52·5 (2·5)		44·2 (1·5)	31·2 (2·5)		44·2 (2·5)	22·1 (2)	
88·4 (5·5)		22·1 (0·5)	62·5 (5)		31·2 (2·5)	44·2 (2·5)	
		44·2 (2)	62·5 (3)		31·2 (2·5)	62·5 (3)	
		88·4 (6)			62·5 (7)		
					15·6 (2)		
					22·1 (2)		
					31·2 (2·5)		
		62·5 (?)			31·2 (3)		
		88·4 (3·5)			44·2 (2·5)		
		88·4 (?)			44·2 (3·5)		
15·6 (1·5)	22·1 (2)	11·0 (1)	7·8 (1)		7·8 (1)	11·0 (1)	
5·6 (2)	22·1 (2)				5·6 (2)	11·0 (2)	
15·6 (1·5)	7·8 (1)				7·8 (1)	5·6 (1)	7·8 (1·5)
11 (1)	11 (1)				3·9 (1)	5·6 (1)	11 (1·5)
11·0 (2)	7·8 (1·5)	15·6 (2)	11·0 (2)		5·6 (2)	5·6 (2)	1·9 (1)
22·1 (3)	7·8 (2)	5·6 (?)	7·8 (?)	15·6 (3)	7·8 (2)	5·6 (2)	3·9 (2)
22·1 (3)	31·0 (3)	5·6 (1)	15·6 (2·5)	15·6 (2·5)	3·9 (1)	7·8 (3)	11·0 (1·5)
		3·9 (1)			3·9 (1)		
22·1 (1)		31·2 (2)	22·1 (1)		22·1 (2·5)	31·2 (1)	
31·2 (2)		11·0 (2)	22·1 (1·5)		5·6 (1)	15·6 (1·5)	
53·3 (2·5)	44·2 (2)		37·5 (2)	44·2 (1·5)	15·6 (2)	31·2 (1)	11·0 (1)
44·2 (2·5	15·6 (1)	15·6 (1·5)	31·2 (2)	26·6 (1·5)	31·2 (1)	22·1 (1)	15·6 (1)
31·2 (2·5)	15·6 (1)	44·2 (2)	31·2 (2)	7·8 (1)	31·2 (1·5)	15·6 (2·5)	
3·9 (2)	5·6 (1)				3·9 (1·5)	3·9 (1)	
5·6 (2)					3·9 (1)	7·8 (2)	
3·9 (1)	5·6 (1)				3·9 (1)	1·9 (1)	5·6 (1)
11·0 (2)	15·6 (1·5)				5·6 (1·5)	3·9 (2)	7·8 (1)
15·6 (2)	22·1 (2)	11·0 (2)	15·6 (2)		3·9 (2)	7·8 (2)	
15·6 (2)	22·1 (2)	11·0 (?)	15·6 (?)		7·8 (2)	3·9 (1)	7·8 (2)
		3·9 (1)			2·8 (1)		
62·5 (1)	44·2 (1)	22·1 (1)	44·2 (1)	31·2 (1)	7·8 (0·5)	44·2 (1)	26·6 (1)
44·2 (1·5)	26·6 (1)	7·8 (1)	15·6 (1·5)	11·0 (1)	7·8 (1)	11·0 (1)	15·6 (1)
31·2 (1)		15·6 (0·5)	31·2 (1)	11·0 (1)	5·6 (0·5)	22·1 (1)	7·8 (1)
62·5 (2)	31·2 (1)	88·4 (1·5)	62·5 (1·5)	22·1 (0·5)	11·0 (0·5)	31·2 (1)	62·5 (1)
62·5 (2)		15·6 (1)	22·1 (2)	22·1 (1)	7·8 (1)	15·6 (1)	31·2 (1)
31·2 (2)	31·2 (1)	125 (2)	22·1 (1)	44·2 (2)	11·0 (2)	31·2 (2)	125 (1)
15·6 (1)		31·2 (1)	11·0 (2)		22·1 (1)	5·6 (1·5)	
22·1 (1)	44·2 (1)	88·4 (1)	7·8 (1)	7·8 (1)	15·6 (1·5)	3·9 (0·5)	7·8 (1)
44·2 (2·5)		44·2 (2)	31·2 (2)		62·5 (1·5)	22·1 (1)	
44·2 (1)	22·1 (1)	62·5 (1)	31·2 (1·5)	7·8 (1)	11·0 (1·5)	22·1 (1·5)	
25 (2)	31·2 (1)	88·4 (2)	44·2 (2)		5·6 (1·5)	26·6 (1·5)	
44·2 (3)		31·2 (3)	62·5 (2)		22·1 (1)	22·1 (1)	
22·1 (1)	22·1 (2)	11·0 (0·5)	44·2 (1·5)	11·0 (1)	5·6 (0·5)	15·6 (1)	11·0 (0·5)
15·6 (2)	11·0 (1·5)	22·1 (2·5)	15·6 (1·5)		5·6 (1·5)	5·6 (1·5)	22·1 (1·5)
52·5 (2·5)	22·1 (1·5)	9·4 (2)	31·2 (2·5)	11·0 (1)	5·6 (1)	11·0 (1·5)	22·1 (2)
15·6 (2)		18·8 (2)	22·1 (3)	15·6 (2)	11·0 (1·5)	15·6 (2·5)	22·1 (2)
37·7 (1·5)		31·2 (1·5)	37·7 (1·5)	62·5 (1)	22·1 (1·5)	37·7 (1·5)	
44·2 (2)		31·2 (3)	15·6 (1)		11·0 (0·5)	26·6 (2)	44·2 (2)
26·7 (1)	15·6 (1)	11·0 (0·5)	7·8 (0·5)	22·1 (1)	5·6 (0·5)	15·6 (1)	7·8 (0·5)

It was this fact that led us to work out regressions of log (*Amplitude* × *time*) on log depth. The regressions fitted the observations well (see Fig. 11, e.g., 30 kc. herrings and frame), but wh slopes of the same object were compared at different frequencies, or when the slopes of differe objects were compared at one frequency, marked differences were observed (see Table VI on p. 2 It will be shown later that this effect also is related to the size of the object and the frequency of t sound used.

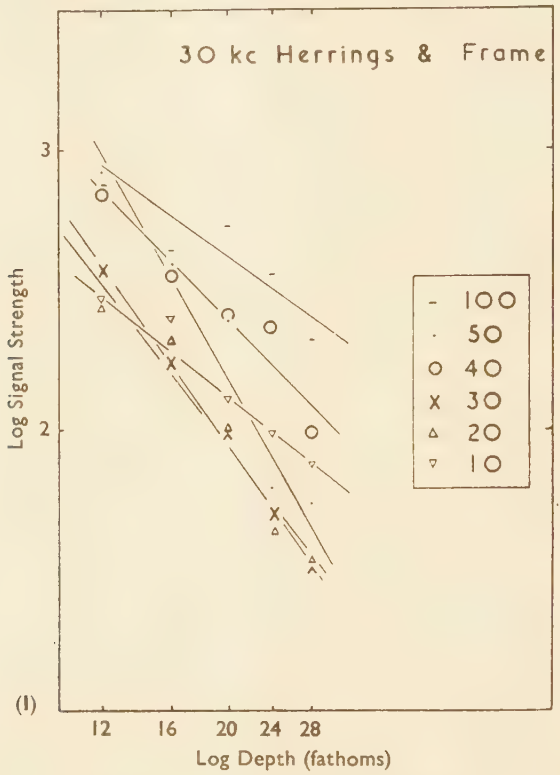


FIG. 11. Regressions of log *Amplitude* × *time* on log depth for herrings + frame, measured on 30 kc.

Finally, at a given depth, a given number of each of the three objects gave different signal streng The echoes from the cod used, which had a cross-sectional area of over 7 times that of the herr were—as might be expected—greater than those from herring, depth for depth; and this necessita the use of different scales in the component diagrams of Fig. 10. The air bladders, however, g echoes which, when corrected for changes of volume with pressure, were comparable with those cod.

2. COMPARISON BETWEEN OBJECTS AT THE THREE FREQUENCIES

The regressions between numbers of objects and signal strength at each depth were used in or to derive values for one object at each depth. The mean of such regressions is the best estimate one object, using all the data. From these regressions, comparable signals were derived by t method shown in Table II (pp. 14–15).

The air bladders were subject to different pressures at different depths, and hence were of differ sizes at different depths. In order to use comparable signals from bladders in the same way those from fish, a correction was applied. It was assumed that the sound scattered from a sph was proportional to the volume of the sphere, so each comparable signal was multiplied $\frac{V_s}{V_d}$ where V_s is the volume at the surface and V_d is the volume at the relevant depth.

The comparable signals are shown in Table IV for each object at each depth, subject to ea frequency.

TABLE IV

Comparable signals per object, using *Total Amplitude* × *time* − *Frame Amplitude* × *time*

od	*10 kc.*	*14 kc.*	*30 kc.*
12 fms.	1·101 ± 0·088	1·087 ± 0·190	2·138 ± 0·726
16 fms.	1·462 ± 0·172	0·796 ± 0·181	1·196 ± 0·227
20 fms.	1·244 ± 0·170	0·888 ± 0·187	1·188 ± 0·188
24 fms.	1·151 ± 0·184	0·780 ± 0·144	0·725 ± 0·077
28 fms.	1·176 ± 0·105	0·773 ± 0·158	0·340 ± 0·115
erring			
12 fms.	0·235 ± 0·040	0·082 ± 0·013	0·121 ± 0·027
16 fms.	0·120 ± 0·033	0·069 ± 0·010	0·116 ± 0·016
20 fms.	0·085 ± 0·011	0·077 ± 0·007	0·150 ± 0·019
24 fms.	0·109 ± 0·010	—	0·132 ± 0·042
28 fms.	0·094 ± 0·021	0·064 ± 0·003	0·105 ± 0·026
110 c.c. air bladder			
rrected for depth			
12 fms.	4·669 ± 1·156	0·947 ± 0·138	2·077 ± 0·428
16 fms.	3·076 ± 0·462	0·828 ± 0·142	2·264 ± 0·612
20 fms.	3·324 ± 0·292	1·117 ± 0·087	2·408 ± 0·397
24 fms.	—	—	2·862 ± 0·336
28 fms.	2·508 ± 0·277	1·315 ± 0·193	2·900 ± 0·500

TABLE IVa

mparable signals per object using $\sqrt{\textit{Total Amplitude}^2 \times \textit{time} - \textit{Frame Amplitude}^2 \times \textit{time}}$

	1 herring at 10 kc.	*1 cod at 30 kc.*
12 fms.	0·159 ± 0·020	1·721 ± 0·140
16 fms.	0·089 ± 0·021	1·631 ± 0·278
20 fms.	0·049 ± 0·021	1·608 ± 0·386
24 fms.	0·083 ± 0·002	1·052 ± 0·156
28 fms.	0·068 ± 0·015	0·398 ± 0·145

ble IV shows three effects. The first and most important is that for 10 kc. cod and 30 kc. ng, the comparable signals for one object are all about the same for all depths, within the es of error. For 10 kc. herring and 30 kc. cod, there is a decline of comparable signal with n, which the errors show to be significant; the 14 kc. results also show a trend but this is ably not significant.

e amount of the decline in comparable signal with depth, expressed in Table IV, appears to be ed to frequency. The decline can be inspected in the table by reading down the columns. As ave noted for 10 kc. cod and 30 kc. herring, there is no significant decline of comparable signal depth. For any of the other four sets of fish results, there is such a decline, which is significant o sets. For any one object, the degree of decrease with depth is in the order of the frequencies. , the signals from cod are constant with depth at 10 kc., and the degree of decrease with depth ases through 14 kc. to 30 kc.

e second point is that if there is a decline of comparable signal with depth, the multiplication *nplitude* × *time* units by the square of the depth to obtain a value of signal strength cannot be ct. The theoretical basis here is that the amplitude of an echo signal measured at the object ld be inversely related to depth; hence the amplitude measured at the receiver should be sely related to the square of the depth. As there is no decline of comparable signal with n for 10 kc. cod and 30 kc. herring, it is concluded that the inverse square relation is being ed by the observations for 10 kc. cod and 30 kc. herring. Conversely, the observations on . herring and 30 kc. cod show a marked deviation from the inverse square relation.

the observations for 10 kc. cod and 30 kc. herring obey the theoretically correct inverse square on, these observations are used to find the difference between comparable signals due to the of the fish.

The third point is that the mean of comparable signals from all depths for the 10 kc. cod is abo 8–10 times the mean of comparable signals for the 30 kc. herring. The ratio of the horizon cross-sectional area of the cod to that of the herring is 7·4. That is to say, the returned signa proportional to the horizontal cross-sectional area of the fish.

These three points will now be considered in more detail.

3. DERIVATION OF A FACTOR FOR AIR BLADDERS

It is probable that the horizontal cross-sectional area is the correct dimension to be used in mak comparisons between cod and herring. Fish were split along the lateral horizontal axis, and outlines of these areas were measured with a planimeter; the results of these measurements are gi in Table V.

In considering the air bladder results, the horizontal cross-sectional area is not the corr dimension, because sound is scattered back to a receiver from a sphere in proportion to the volu of the sphere. So that all observations could be used, the mean volume of the air bladders at depths was used. This mean volume is included in Table V.

This table consists of two parts. The first shows the derivation of comparable signals per u area or per unit volume; such values are the mean of all depths for one object at one frequen These values are used in the second part of the table to derive ratios between cod and air blad values, and between herring and air bladder values, for each frequency. These are quite wid different and so a mean value for the comparison between fish material and air was derived.

It will be noticed that we have used the cross-sectional area for fish and the volume of the bladder. The quantity of sound scattered back to a receiver from any object that is smaller th (where λ is the wavelength of sound) is proportional to the volume of the object; the same is t of a sphere even if it is larger than one wavelength. For an object that is not a sphere, the quan of sound scattered back to the receiver is proportional to the cross-sectional area. A fish m well be considered as an ellipsoid, rather comparable to a sphere. A case could well be mad the comparable signals from fish being reduced by volume. Table V shows a fish : air ratio (1 : 7· derived, assuming that the quantity of sound returned to the receiver is proportional to the cr sectional area of the fish and to the volume of the air bladder. If it is proportional to the vol of the fish and to the volume of the air bladder, the fish : air ratio would be 1 : 95·50. It is prob that the right estimate lies between these two.

An air bladder occupies 5 per cent of the fish's volume. By the first ratio, one would expect the signal returned from the air bladder was about 40 per cent of that returned from the fish; the second ratio one would expect that the signal returned from the air bladder was five times returned from the fish. Using the signal strength values for 1 cod and 1 air bladder at all th frequencies, it may be shown that the signal returned from the air bladder was on the aver 79 per cent of that returned from the fish. This estimate, which is derived independently from t in Table V, shows that the fish : air ratio of 1 : 7·86 should possibly be increased to 1 : 15.

TABLE V

The use of the comparable signals to make a ratio between fish material and air

		10 kc.		14 kc.		30 kc.	
	Area or Volume	*C.S.*	*C.S. per cm² or cm³*	*C.S.*	*C.S. per cm² or cm³*	*C.S.*	*C.S. per cm² or cm*
1 Cod	344·25 cm²	1·227	0·0036	0·865	0·0025	1·117	0·0032
1 Herring ...	46·40 cm²	0·129	0·0028	0·073	0·0016	0·125	0·0027
1 Bladder ...	24·72 cm³	0·848	0·0343	0·243	0·0098	0·556	0·0225

Derivation of comparable signals per unit area or unit volume

	10 kc.	14 kc.	30 kc.
Cod : bladder	9·53	3·92	7·03
Herring : bladder ...	12·25	6·12	8·33

Mean value of Fish : air— 1 : 7·86.

Derivation of a ratio between fish material and air

he air bladder is between eight and fifteen times as efficient as the material in returning sound receiver, 40–80 per cent of the returned signal from fish may be attributed to the air bladder, occupies 5 per cent of the volume of the fish. There are three ways in which this value be an incorrect estimate. The first point is that as the air bladders decrease in size with sing depth, there may be an unknown relation with frequency at different depths. For this , a mean may not be an appropriate estimate. The second is that the air bladders used in xperiments were hung in the water, sound being scattered back from an air/water boundary; sh, sound is scattered back from an air/fish-flesh boundary. There is a difference in density n water and fish flesh, but this difference will not reduce the estimate of the air bladder effect uch. The density of fish muscle is 1·0533, so the impedance across a muscle/air boundary less than that across a fresh-water/air boundary by a small quantity, perhaps 5 per cent. The oint is that the air bladder in fish is rarely spherical and the correct theoretical formulation scattering of sound by different shapes of air bladder is likely to be more complex than that d, and its response to different frequencies is likely to vary with depth differently from the elf.

E DEVIATION FROM THE INVERSE SQUARE RELATION EXPRESSED Y REGRESSIONS OF LOG "SIGNAL STRENGTH" ON LOG DEPTH

as shown above that there was a deviation from the inverse square relation between signal h and depth. In order to find the extent of this deviation, regressions were calculated of log strength on log depth for each number of objects. The values of signal strength used here e the frame, because it was thought that the whole complex signal should be used. It could ued that differences between frequencies might be attributed to the frame, but it could not be that differences between objects should be. Again, if the result obtained by this method is me as that obtained by the method of comparable signals, we may conclude that neither d of dealing with the frame is very misleading.

slopes of the regressions were calculated. These varied from $-1{\cdot}0408$ to $-4{\cdot}1221$. The oint of interest was how far these slopes deviated from the expected value of -2. Table VI the slope of each regression for each set of objects at each frequency and the probability that pe is -2.

means of each series in Table VI show that the slope of the regressions for 10 kc. cod are not antly different from -2 but that the slope of the regressions for 30 kc. is significantly different - 2. Thus one would expect that of the two frequencies, sounding on cod, the 10 kc. machine be most effective in deep water because the signal strength from cod at 30 kc. decreases in xperiments as the inverse cube and not as the inverse square.

same type of trend may be observed in the results for the herring. With decreasing frequency, an slope increases from $-2{\cdot}2955$ at 30 kc. to $-2{\cdot}7020$ at 10 kc., of which the latter is signifi- different from -2 at $P = <0{\cdot}01$. The results for the air bladders show the same sort of of slope with frequency.

le VI shows not only are there marked differences in slope of the regression between fre- es, but that there are also differences in slope between objects. This is the same type of sion as the first one drawn from Table IV (p. 21), i.e., that there are differences in comparable between objects as well as between frequencies. Thus the size of the object is of the same of importance as the frequency of the sound used.

TABLE VI

Slopes of regression (A_1) of log " signal strength " on log depth. P is the probability that the slope is –2

	10 kc.		14 kc.		30 kc.	
	A_1	P	A_1	P	A_1	P
Cod						
1	−2·1135	0·09	−1·8393	0·8	−3·8531	<0·01
4	−1·5784	<0·01	−2·0785	0·9	−3·1128	0·3
5	−2·2885	0·2	−2·5500	0·09	−2·8068	0·3
8	−1·4023	0·2	−2·0372	>0·9	−2·4713	0·6
12	−1·8048	0·7	−1·5137	0·2	−2·9331	0·4
16	−1·5760	0·4	−2·0758	0·6	−4·1221	<0·01
Means ...	−1·7939	0·1	−2·0158	>0·9	−3·2165	<0·01
Herring						
10	−2·6391	0·05	−1·8251	0·5	−1·7394	0·3
20	−1·9261	0·8	−1·8073	0·6	−2·6727	0·2
30	−2·7546	0·2	−2·0356	0·9	−2·9002	<0·01
40	−2·6490	0·2	−2·5510	0·2	−2·0261	>0·9
50	−3·0869	0·4	−2·8558	<0·01	−3·1461	0·05
100	−3·1562	0·1	−2·7225	0·1	−1·2886	0·2
Means ...	−2·7020	<0·01	−2·2996	0·01	−2·2955	0·04
Bladder						
1	−2·6697	<0·01	−2·4984	0·07	−2·1657	0·8
4	−3·0591	0·1	−2·0661	0·9	−2·2919	0·6
5	−2·0559	>0·9	−3·0197	0·2	−2·2116	0·5
8	−3·0986	<0·01	−2·3886	0·2	−1·0408	<0·01
12	−2·6038	0·3	−2·3179	0·5	−2·1766	0·5
16	−2·5465	0·09	−2·2886	0·5	−2·4925	0·4
Means ...	−2·6723	<0·01	−2·4299	0·01	−2·0632	0·7

Note : For the 14 kc. observations, there were only 15 cod and 15 bladders.

5. THE RELATION BETWEEN SIZE OF OBJECT AND THE FREQUEN OF THE SOUND USED

Table V gives the horizontal cross-sectional areas of cod and herring; in this dimension, th is 7·4 times as large as the herring. Thus to use the comparable signals from cod and he together, the latter must be multiplied by 7·4. Table VI shows that there are differences, be the slopes of the regressions of log signal strength on log depth, associated with frequency in direction (across columns) and with size of object in the other (down rows). These difference such that we should expect the greatest differences in magnitude of comparable signal bet frequencies to be found in deep water. So the comparable signals from herring and cod, use showing the differences between frequencies, are taken from 28 fathoms. These results are sh in Table VII.

It has been shown that for one object marked differences in comparable signal occur bet frequencies. This must be because some dimension of the object bears different relationships t different wavelengths of sound. This argument is reinforced when it is remembered that sig differences in comparable signal are found between different-sized objects at the same frequ The theoretical basis of such a relation is unknown; however, in order to present the results simple way, we have assumed that the significant dimension of the object is the dorsiventral the dimension along the direction on which the sound waves travel.

The relation between the size of the object and the wavelength of the sound is expressed in ratio $\frac{d}{\lambda}$, where d is the dorsiventral dimension of the object and λ is the wavelength of the sc These ratios are set out in Table VII.

TABLE VII

different-sized objects at different frequencies ; λ at 17 C. in pure water. Comparable signals om Table IV ; mean slopes of series of regressions of log *Amplitude* × *time* on log depth from able VI

d	Cod 12·6 cm.			Herring 6·5 cm.			110 cc. air bladder 3·568 cm. at 20 fms.		
	$\frac{d}{\lambda}$	*Comparable signal*	*Mean slope of series*	$\frac{d}{\lambda}$	*Comparable signal* × 7·4	*Mean slope of series*	$\frac{d}{\lambda}$	*Comparable signal*	*Mean slope of series*
cm.	0·85	1·176± 0·105	−1·7939 (p 0·1)	0·44	0·697± 0·156	−2·7020 (p<0·01)	0·24	—	−2·6723 (p <0·01)
cm.	1·20	0·773± 0·158	−2·0158 (p>0·9)	0·62	0·475± 0·022	−2·2996 (p 0·01)	0·34	—	−2·4299 (p 0·01)
:m.	2·56	0·340± 0·115	−3·2165 (p<0·01)	1·32	0·779± 0·193	−2·2955 (p 0·04)	0·73	—	−2·0632 (p 0·7)

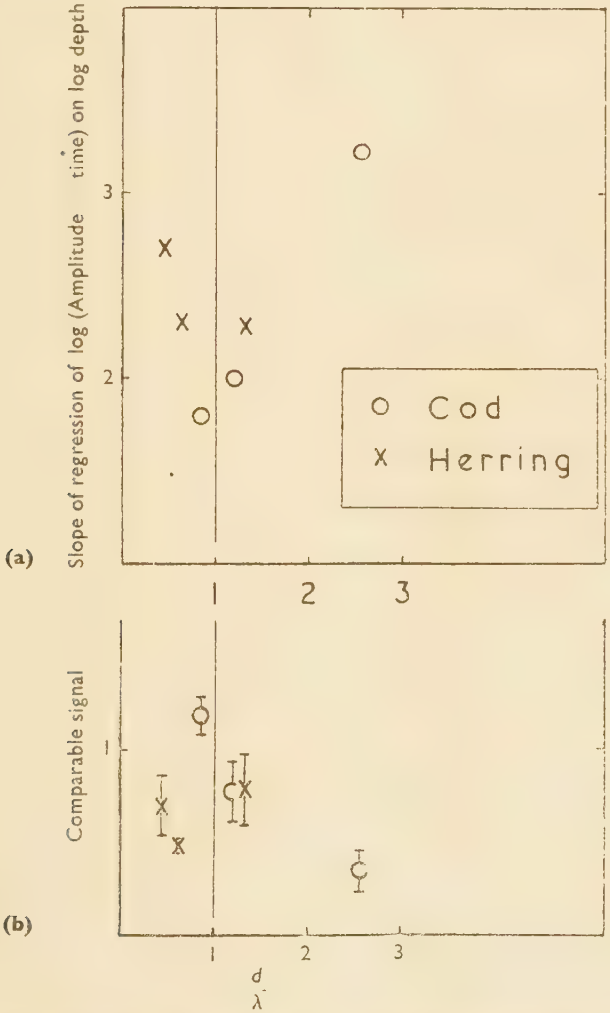
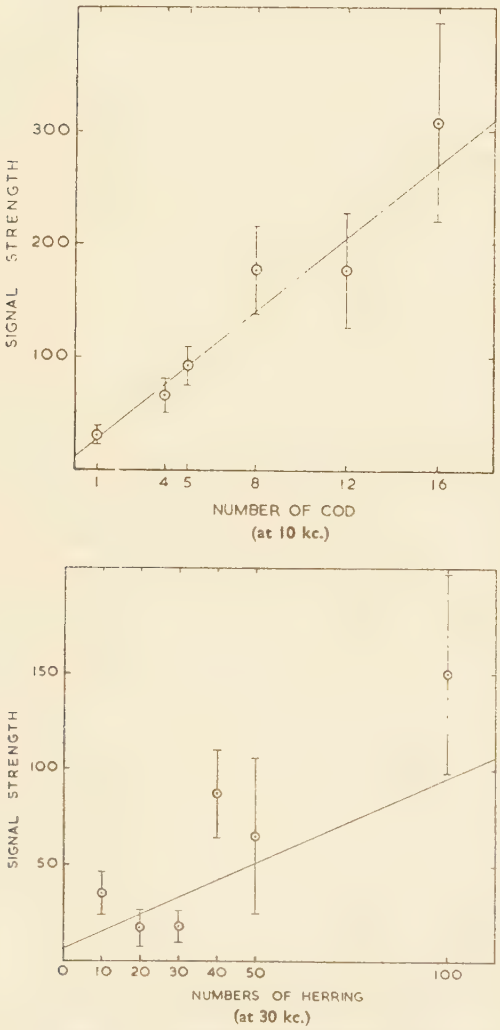


FIG. 12. The relation between $\frac{d}{\lambda}$ and (a) the slope of regression of log *Amplitude* × *time* on log depth, (b) comparable signals at 28 fms.

Table VII summarizes the results from Tables IV, V and VI. The first result is that the com
able signal at 28 fathoms is largest when $\frac{d}{\lambda}$ approximates to 1. This is over a range of $\times$ 3, w
is far beyond the permissible errors that are given. No comparable signals are quoted for th
bladders; these results were too complicated for this purpose, because the air bladders were
different size at each depth. The second result is that the mean slopes of the depth series te
approach most closely to -2 when $\frac{d}{\lambda}$ approximates to unity.

Fig. 12 expresses the same result diagrammatically. There are two parts to this figure : (*a*
relation between $\frac{d}{\lambda}$ and the slope of the regression of log *Amplitude* $\times$ *time* on log depth; (*b*
relation between $\frac{d}{\lambda}$ and the comparable signals at 28 fms. There is some evidence that the maxi
comparable signal is obtained when $\frac{d}{\lambda} = 1$; also there is some evidence that when $\frac{d}{\lambda} = 1$, the
of the regression of received signal on depth most nearly approaches -2. It must be pointe
that there is not a continuous series of observations on one species and that we have treated co
herring merely as objects. Again, the comparable signals for herring have been multiplied by



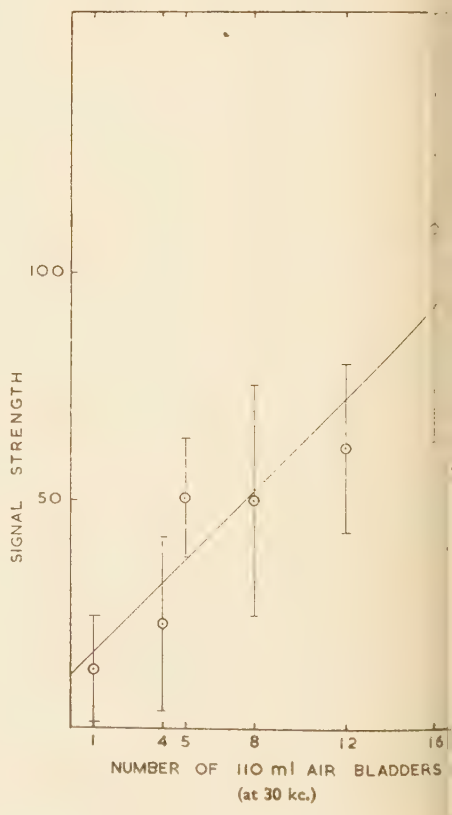


FIG. 13. The relation between the mean returned " signal strength " for all depths and numbers of cod herring, and 110 c.c. air bladders.

xplanation is put forward to account for the results given in Table VI. It is realized, however, fferences between scattering distributions from different-sized objects at different frequencies well account for the type of result obtained.

are now able to return to our first observation, given in Table I, Part I (p. 5). This gives ults of some frequency comparisons made at sea. On herring shoals, the 30 kc. machine out one and three-quarter times as effective as the 14 kc.; on cod shoals, the 10 kc. machine ice as effective as the 14 kc. This result on the actual fish shoals is in accord with the experi- in Windermere. In the R. V. ERNEST HOLT, a **30 kc.** 1,500 volt contactor box sounder was ongside a **10 kc.** 2,000 volt contactor box machine. Frequently, the observation was made, dentified shoals of fish, that the 30 kc. machine gave better results down to 30 fathoms than did kc.; yet the 10 kc. machine gave better results below that depth. The differences were too l to be due to differences in attenuation. A possible conclusion is that these machines were ng on small fish down to 30 fathoms and on larger fish at greater depth, because capelin are n in arctic surface waters and cod are common at greater depths.

THE RELATION BETWEEN "SIGNAL STRENGTH" AND NUMBERS

comparable signals in Table IV are derived from linear regressions of signal strength on rs. A linear regression was used because there were not enough observations in each set nguish between a linear regression and any curvilinear one. The intention in using the linear ion was to make some estimate of the error to be attached to the mean signal strength.

e objects were randomly distributed with respect to one wavelength, signal strength should be to the square root of the numbers. From these experiments, the mean signal strength for ths (12, 16, 20, 24, and 28 fathoms) can be plotted against numbers. This was carried out for bject at those frequencies from which there is no deviation from the inverse square relation. sults are presented in Fig. 13. The variance on each observation increases with increased rs; the linear regression line was fitted by weighting the components of regression by the cal of the variance on each observation. The results can be represented empirically by a t line, but its precise form is unknown. This relation points to the possibility of estimating mber of fish (of one known species) within one sounding.

7. ADDITIONAL RESULTS

xperiment was carried out on live perch to find out whether their behaviour was modified by nsmission of sound. Two frames were suspended about a foot-and-a-half apart just below ntoons; they supported a cage of shrimp netting. Into this cage we put 100 live perch; ere taken from traps in shallow depth. The cage could be seen from either side of the two ns or in the gap between them. The behaviour of the fish was observed with the sounder on at each of the three frequencies; no modification of their behaviour was seen. In fact, one fish appeared outside the cage, presumably attracted by the dense shoal. This confirms the ation of Schärfe (1951) on carp, perch, tench, *Amiurus nebulosus*, *Cobitis fossilis*, and *nus wartmanni*.

ection 7 of Part I we have referred to the disturbance that was observed at 5 fathoms. This obably associated with a thermocline. The temperature difference across the discontinuity C. in 5 m. The trace on the paper record and the signals on the oscilloscope were longer than lse length, which suggests that there might have been an accumulation of material, living or n depth above the physical discontinuity. Schüler (1951), Krefft and Schüler (1951) claim ey have found thermoclines which extend over many pulse lengths; these were not related to easurements of temperature. Joseph (1949, 1950) has shown conclusively that there is often dity layer associated with the thermocline. This is unidentified and may be due to plankton itus resting in a sharply defined layer on the density discontinuity. Recently, Trout, Lee, dson, and Harden Jones (1952) have published echo traces associated with multiple thermo- each of which is of the order of one pulse length in duration.

8. DISCUSSION

There are three main results from this series of experiments: the proportion of returned s due to the air bladder; the relation between numbers and signal strength; the relation betwee size of the object and the wavelength of the sound used.

Assuming that returned signal strength varied in proportion to the lateral cross-sectional ar the fish and to the volume of the sphere of the air bladder, an empirical fish/air factor was de This led to the result that the air bladder taking up 5 per cent of the volume of the fish responsible for 40–80 per cent of the returned signal. Again, it must be pointed out that air bladders were spheres and that they were used outside the fish, so the water/air boundar the scattering surface and not the fish-flesh/air boundary.

Fig. 18 of Hodgson (1950) shows the very thin trace that is given by a dense mackerel Again, the shallow scattering layer that was found in the western English Channel by Bur Lee (1951) has been shown to consist predominantly of larval pilchards that have just acquired air bladders; similar layers have been found to consist of larval gobies.

An analysis of the correct proportion of the returned signal that is due to the air bladder v difficult. This is because the speed of sound in fish materials is unknown, because the air bla of different fishes are of different shapes, and lastly because the air bladder might possibly c its shape during the life of one fish, especially during the spawning season. It must be conc that at the moment, the empirical approach to this problem is the only possible one.

The second result is that there is a relation between numbers and signal strength. The t theoretical function is unknown. Its derivation would be complex in view of the increase duration of the signal with numbers (Fig. 9, p. 12). A lot depends on whether this incre duration of signal is really an effect of increased numbers or whether it is an artefact in the of measurement. It might be expected that the increased duration of the signal was due to th that the net sagged when more fish were tied on, thus increasing the distance from the oscill some of the fish. This is unlikely, as shown above. There is no explanation at the moment, increase in duration of signal, unless there is some form of multiple scattering; we did not that the signal died away with time to a greater extent with increasing numbers, as would hav expected. As we have no photographic records of our results, we cannot check thi adequately.

Theoretically, a square root relation between signal strength and numbers is more likely linear one. However, until the cause of the increased duration of signal with numbers is k a search for the correct function is not worth while. The important point at this stage is might be possible to estimate the numbers of identified fish on the axis at one depth *in one sou* It would also be possible to extend this, applying it to the whole sound envelope, but one woul to assume that the fish were randomly distributed across the sound envelope at the depth in qu

The third result is the relation between the wavelength of sound used and the size of the It has been shown in these experiments that the magnitude of signal returned from fish at depth varies in accordance with the wavelength. In order to simplify the relation we have sa the maximum signal is returned when the ratio of the dorsiventral dimension of the object wavelength most nearly approaches 1. The departure from this relation was shown to be to a departure from the inverse square relation between the returned signal and depth; the dep took the direction towards an inverse cube relation.

Again it might be suggested that this effect is a consequence of measuring the duration signal along the time base. However, the effect as measured by the regressions of log strength on log depth is present when there is only one or four fish on the frame, in which c duration of the signal cannot have been increased merely in the measuring system. It mig be suggested that the effect was a consequence of our method of subtracting the frame valu the *Amplitude* × *time* values. As the regressions of log signal strength on log depth incl frame, this objection cannot be sustained.

There is no explanation at the moment for this relation with frequency. It might be a of scattering from cylinders, or it might even be an effect of multiple scattering. It does, h raise the possibility that fish of different sizes might be identified within one sounding, by

e or more frequencies. The little evidence that we have from marine observation does support ea. If the phenomenon is properly demonstrated at sea, and it does become possible to fy fish within one sounding, there are two possibilities:

that one could make an estimate of the number of identified fish within one sounding;
that one could make an echo survey of identified fish.

as suggested in Part I that identification of fish traces by their appearance on the record paper ted to estimating the size of the shoal. Thus an echo survey over a wide region, and over more ne day and one night, is going to record on the one hand different species, and on the other fish of one species behaving differently. There is often no way of distinguishing between two cases, and the identification made on an echo survey is not an identification of each fish but is a general identification. Such a general identification has been made by fishermen they expect the fish that appear off East Anglia in the autumn to be herring. The use of a frequency sounder, however, might make it possible to identify each fish trace on a survey.

SUMMARY

DEAD fish were hung in their swimming positions from netting stretched across a frame, whi its turn was suspended beneath an echo sounder. Observations were made on different nur of cod, herring, and 110 c.c. air bladders at different depths. Signals were matched on a C with a signal injector put in the circuit between the receiver and the amplifier.

It was found that the duration of signal increased with increasing numbers of fish. The cau this is unknown, but as a consequence signals were measured as *amplitude* × *duration* rather as amplitude. Estimates of signals from fish were made by subtracting the value of *amplitu duration* due to the frame from the total value due to frame and fish. Tests showed that this ment gave the same order of result as the use of

$$\sqrt{Total\ (amplitude^2 \times duration)} - \sqrt{Frame\ (amplitude^2 \times duration)}.$$

Three main results were obtained:

(a) The air bladder, which takes up 5 per cent of the volume of the fish, is probably respo for 40–80 per cent of the returned signal.

(b) There was a roughly proportional relation between numbers of fish and the returned s

(c) The magnitude of the signal returned from fish at a given depth varies in accordance w wavelength. The maximum signal appears to be returned when the ratio of the dorsiv dimension of the object to the wavelength of the sound used most nearly approaches 1. is a brief way of expressing what is probably a complex phenomenon. The departure this relation was shown to be related to a departure from the inverse square relation be the returned signal and depth; the departure took the direction towards an inverse relation. Thus the differences between frequencies on one object increased with dept

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APPENDIX TABLE

Depth	*10 kc.*	*14 kc.*	*30 kc.*
fms.	%	%	%
12	21·1 (S)	42·9 (Not S)	89·9 (Not S)
16	31·2 (S)	60·1 (Not S)	50·3 (Not S)
20	36·2 (S)	55·7 (Not S)	41·9 (Not S)
24	42·2 (S)	45·1 (Not S)	28·1 (S)
28	23·7 (S)	54·2 (Not S)	89·0 (Not S)

Depth	*10 kc.*	*14 kc.*	*30 kc.*
fms.	%	%	%
12	45·5 (S)	40·9 (S)	58·5 (Not S)
16	72·5 (Not S)	39·6 (S)	36·6 (Not S)
20	33·2 (S)	25·4 (S)	33·1 (S)
24	22·6 (S)	—	84·0 (Not S)
28	58·6 (Not S)	13·7 (S)	64·2 (S)

Depth	*10 kc.*	*14 kc.*	*30 kc.*
fms.	%	%	%
12	65·5 (Not S)	38·9 (S)	54·7 (S)
16	36·7 (Not S)	45·9 (S)	71·5 (S)
20	23·4 (S)	20·4 (S)	43·8 (S)
24	—	—	31·1 (Not S)
28	29·4 (S)	39·1 (Not S)	45·8 (S)

s of $\frac{\sigma\sqrt{1+\frac{1}{n}\cdot 100}}{\bar{y}}$ for regressions of signal strength on numbers for each object at each depth and each
:y. (S) means that the regression is significant at p. 0.05 ; (Not S) means that it is not significant

σ is the standard deviation from regression

n is the number of observations

$\bar{y}$ is the mean signal strength

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